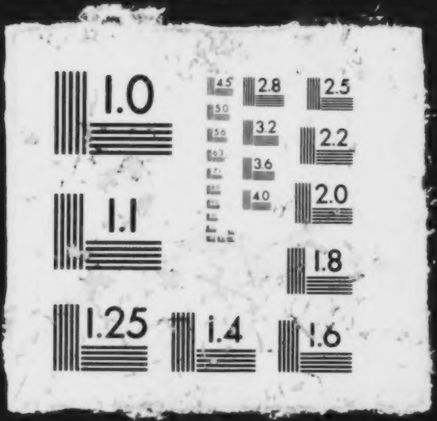
1 OF 5

PB83

192385


1.0
4.5
5.0
5.6
6.3
7.1
8.0
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

PB83-192385

Background Information Document
Proposed Standards for Radionuclides

(U.S.) Office of Radiation Programs
Washington, DC

Mar 83

U.S. Department of Commerce
National Technical Information Service
NTIS

PB83-192385

United States
Environmental Protection
Agency

Office of
Radiation Programs
Washington DC 20460

EPA 520/1-83-001
March 1983

Radiation

EPA

Background Information Document

Draft

Proposed Standards for Radionuclides

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA 520/1-83-001

2.

3. RECIPIENT'S ACCESSION NO.
PB83 192385

4. TITLE AND SUBTITLE
Draft Background Information Document
Proposed Standards for Radionuclides

5. REPORT DATE
March 1983

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Environmental Protection Agency
Office of Radiation Programs
Washington, D.C. 20460

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS

13. TYPE OF REPORT AND PERIOD COVERED
Draft

14. SPONSORING AGENCY CODE
200/03

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report presents background information that supports the Environmental Protection Agency's (EPA's) proposed emission standards for radionuclides pursuant to Section 112 of the Clean Air Act. An analysis of public health impacts from the following source categories is presented: (1) Department of Energy (DOE) facilities, (2) Nuclear Regulatory Commission (NRC)-licensed and non-DOE Federal facilities, (3) coal-fired utility and industrial boilers, (4) uranium mines, (5) phosphate industry facilities, and (6) mineral extraction industry facilities. For each source category, the following information is presented: (1) a general description of the source category, (2) a brief description of the processes that lead to the emission of radionuclides into air, (3) a summary of emissions data, and (4) estimates of radiation doses and health risks to both individuals and populations.

This is a draft document. After a public comment period, it will be revised as necessary and issued in final form when the standards are promulgated.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Clean Air Act Radionuclides Radon DOE Facilities (Department of Energy) Nuclear Regulatory Commission licensed Facilities Uranium mines Phosphate Industry		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA 520/1-83-001

Draft

Background Information Document

Proposed Standards for Radionuclides

March 1983

U.S. Environmental Protection Agency
Office of Radiation Programs
Washington, D.C. 20460

CONTENTS

Page

1. INTRODUCTION 1-1

2. DEPARTMENT OF ENERGY FACILITIES

Summary 2.0-1
2.1 Argonne National Laboratory 2.1-1
2.2 Brookhaven National Laboratory 2.2-1
2.3 Fermi National Accelerator Laboratory 2.3-1
2.4 Hanford Reservation 2.4-1

2.5 Idaho National Engineering Laboratory 2.5-1
2.6 Lawrence Livermore National Laboratory 2.6-1
2.7 Los Alamos National Laboratory 2.7-1
2.8 Oak Ridge Reservation 2.8-1
2.9 Paducah Gaseous Diffusion Plant 2.9-1

2.10 Portsmouth Gaseous Diffusion Plant 2.10-1
2.11 Rocky Flats Plant 2.11-1
2.12 Savannah River Plant 2.12-1
2.13 Feed Materials Production Center 2.13-1
2.14 Ames Laboratory 2.14-1

2.15 Battelle-Columbus Laboratory 2.15-1
2.16 Bettis Atomi Power Laboratory 2.16-1
2.17 Knolls Atomic Power Laboratory 2.17-1
2.18 Lawrence Berkeley Laboratory 2.18-1
2.19 Mound Facility 2.19-1

2.20 Nevada Test Site 2.20-1
2.21 Pantex Plant 2.21-1
2.22 Pinellas Plant 2.22-1
2.23 Rockwell International Corporation 2.23-1
2.24 Sandia National Laboratories 2.24-1
2.25 Shippingport Atomic Power Station 2.25-1
2.26 Stanford Linear Accelerator Center 2.26-1
2.27 Worldwide Impact of Selected Radionuclides 2.27-1
2.28 Future operations at DOE Facilities 2.28-1
    2.28(A) Resumption of Operations at the PUREX Plant 2.28-1
    2.28(B) Resumption of L-Reactor Operations at the Savannah River Plant 2.28-3

CONTENTS (Continued)

Page

3. NRC-LICENSED FACILITIES AND NON-DOE FEDERAL FACILITIES

3.1 Research and Test Reactors 3.1-1
3.2 Accelerators 3.2-1
3.3 Radiopharmaceutical Industry 3.3-1
3.4 DOD Facilities 3.4-1
3.4A Armed Forces Radiobiology Research Institute 3.4A-1
3.4B U.S. Army Facilities 3.4B-1
3.4C U.S. Navy Facilities 3.4C-1
3.5 Radiation Source Manufacturers 3.5-1

4. COAL-FIRED UTILITY AND INDUSTRIAL BOILERS 4.0-1

4.1 Utility Boilers 4.1-1
4.2 Industrial Boilers 4.2-1

5. URANIUM MINES 5-1

6. PHOSPHATE INDUSTRY FACILITIES

6.1 Phosphate Rock Processing Plants 6.1-1
6.2 Wet Process Fertilizer Plants 6.2-1
6.3 Elemental Phosphorus Plants 6.3-1

7. MINERAL EXTRACTION INDUSTRY FACILITIES

Metal Mines, Mills, and Smelters
7.1 Aluminum Industry 7.1-1
7.2 Copper Industry 7.2-1
7.3 Zinc Industry 7.3-1
7.4 Lead Industry 7.4-1

APPENDICES

A. ASSESSMENT METHODOLOGY A-1

B. THE BASIS FOR RISK ESTIMATES B-1

C. CALCULATIONS OF RADON-222 CONCENTRATIONS C-1

Chapter 1: INTRODUCTION

The purpose of this report is to serve as a background information document in support of the Environmental Protection Agency's (EPA) proposed standards for sources of emissions of radionuclides pursuant to Section 112 of the Clean Air Act. It presents an analysis of the public health impact caused by radionuclides emitted into the air from facilities that are the subject of this rulemaking.

These facilities are examined as six major source categories:

(1) Department of Energy (DOE) facilities

(2) Nuclear Regulatory Commission (NRC) licensed(1) and non-DOE Federal facilities

(3) Coal-fired utility and industrial boilers

(4) Uranium mines

(5) Phosphate industry facilities

(6) Mineral extraction industry facilities

For each source category, we present the following information:

(1) A general description of the source category

(2) A brief description of the processes that lead to the emission of radionuclides into air

---

(1)Sources are licensed by the Nuclear Regulatory Commission (NRC) or States that have entered into an agreement with the NRC whereby certain regulatory authority is relinquished by the NRC and assumed by the States pursuant to Section 274 of the Atomic Energy Act of 1954, as amended.

(3) A summary of emissions data

(4) Estimates of the radiation doses and health risks to both individuals and populations

This is a draft document. After a public comment period, it will be revised as necessary and issued in final form when the standards are promulgated.

Emission Data

Insofar as possible, measured radionuclide emission data were used to estimate health impacts. In the absence of measured data, estimates were used that were based on calculated or extrapolated values. The data for DOE facilities were obtained from DOE's Effluent Information System for the calendar year 1981 (DOE81); the data for NRC-licensed facilities were obtained from NRC annual effluent reports; and the data for the other categories, such as coal-fired utility and industrial boilers, uranium and nonuranium mines, and the various extraction industries, were usually obtained from special reports prepared on contract for the EPA.

Health Impact Assessment

The public health assessment includes estimates of the following radiation exposures and health risks:

(1) Dose-equivalent rates to the individuals at highest risk (maximum individual)

(2) Collective dose-equivalent rates to population groups

(3) Lifetime risks to the maximum individuals in the exposed population

(4) The number of fatal cancers committed in the exposed population per year of facility operation

The health risks estimated in this report are for fatal cancers only. Our current practice is to assume that for whole body exposure, the number of genetic health effects and the number of nonfatal cancers are each about the same as the number of fatal cancers (EPA77).

Assessment Methodology

DOE facilities were analyzed individually on a site-by-site basis. The NRC- and State-licensed facilities, DOD facilities, and the facilities emitting naturally-occurring radionuclides were grouped together into source categories on the basis of similarity of activities or operations and analyzed by selecting a reference facility that represents the source category. Dose and risk were calculated by using AIRDOS-EPA and RADRISK computer models developed by Oak Ridge National Laboratory under contract to the EPA. These computations are based upon the latest information on transport, uptake, and metabolic behavior of the various radionuclides and are described in detail in a recent EPA report (EPA79).

Information on emission control technology for facilities in this report is published in documents that are available in Docket A-79-11, Central Docket Section, Gallery One, West Tower Lobby, EPA, 401 M Street, S.W., Washington, D.C.

The Maximum Individual

Dose-equivalent rates and radon decay exposures are presented for the maximum individual. Each location on the assessment grid is assessed to determine the lifetime risk to an individual from all pathways. The position on the grid that provides the greatest calculated lifetime risk is considered to be the location of the maximum individual.

The dose rates presented for the maximum individual are 70-year committed dose equivalents. This is also the dose-equivalent rate in the 70th year following the start of exposure.

Radon decay exposures presented for the maximum individual are the radon-222 decay product levels to which an individual would be exposed assuming 70-percent equilibrium (i.e., 100 pCi/L radon-222 = 0.7 WL).

Regional Population

The term regional population refers to the population living within a radius of 80 kilometers of a source unless otherwise noted in the text. For a few source categories, exposures are presented for the population of the United States or the World, and these cases are specifically identified in the appropriate tables.

Collective dose-equivalent rates and radon decay product exposures are expressed in units of person-rem/year and person-working levels, and are the sum of the dose-equivalent rates or radon decay product exposures to all the individuals in the exposed population due to the releases from a source. Further details of these calculations are contained in Appendix A.

Individual Lifetime Risk and Number of Fatal Cancers

The individual lifetime risk is the probability of fatal cancer to an individual due to a lifetime of exposure (70 years on the average) to the concentrations of radionuclides estimated for that individual.

The number of fatal cancers per year is that potential number of cancers in the population committed by one year's release of radionuclides from the facility. They are expected to occur many years after the year in which the releases take place.

Numeric Notation and Units

Throughout this report, numeric values are frequently expressed in a modified scientific format. For example, 0.00123, which is equal to 1.23×10^{-3}, may be expressed as 1.23E-3; 3210, which is equal to 3.21×10^{3}, may be expressed as 3.21E+3.

Metric units have been used for reporting data, except in a few instances where referenced data are presented in the original units.

REFERENCES

BEIR72 Advisory Committee on the Biological Effects of Ionizing Radiation, The Effects of Population Exposures to Low Levels of Ionizing Radiation, National Academy of Sciences, Washington, D.C., 1972.

DOE81 Department of Energy, Effluent Information System (EIS), Calendar year 1981, DOE, Washington, D.C.

EPA77 Environmental Protection Agency, Radiological Quality of the Environment in the United States, EPA 520/1-77-009, Office of Radiation Programs, Washington, D.C., 1977.

EPA79 Environmental Protection Agency, AIRDOS-EPA, A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides, EPA 520/1-79-009, December 1979.

Mo77 Moore R.E., The AIRDOS-II Computer Code for Estimating Radiation Dose to Man from Airborne Radionuclides in Areas Surrounding Nuclear Facilities, ORNL-5245, Environmental Sciences Division Publication No. 974, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830, 1977.

Chapter 2: DEPARTMENT OF ENERGY FACILITIES

Summary

The radiation doses and risks of fatal cancers to individuals and populations around Department of Energy facilities were estimated using the methods in Appendices A and B. These estimates are summarized in Tables 2-A through 2-D. More detailed information, including a general description of the facility, a summary of the processes causing the emissions, estimates of the amount of emissions, and more detailed estimates of dose and risk are found in the respective sections of this chapter.

Table 2-A. Summary of dose rates and risks to nearby individuals for facilities with the largest emissions

Facility	Principal emissions		Maximum individual		
	Radionuclide	Quantity (Ci/y)	Principal organ	Dose rate (mrem/y)	Risk(a) (x 10^{-6})
Argonne National Laboratory	Ar-41	0.4	Pulmonary	<0.1	0.0006
	Kr-85	6.7	Bone(b)	<0.1	
			Muscle	<0.1	
			Red marrow	<0.1	
Brookhaven National Laboratory	H-3	660	Pulmonary	0.4	9
	O-15	36,000	Bone(b)	0.6	
	Ar-41	170	Muscle	0.5	
	Xe-127	2.3	Red marrow	0.5	
Feed Materials Production Center	U-234	0.11	Pulmonary	88(c)	200
	U-238	0.11	Bone(b)	26	
			Red Marrow	1.8	
			Kidneys	12	
Fermi National Accelerator Laboratory	H-3	0.42	Bone(b)	0.7	10
	C-11	1500	Muscle	0.6	
			Red marrow	0.7	

See footnotes at end of table.

Table 2-A. Summary of dose rates and risks to nearby individuals for facilities with the largest emissions (Continued)

Facility	Principal emissions		Maximum individual		
	Radio-nuclide	Quantity (Ci/y)	Principal organ	Dose rate (mrem/y)	Risk[a] (x 10^{-6})
Hanford	H-3	18	Pulmonary	2	40
Reservation	Ar-41	65,000	Bone[b]	2	
100 Area	Kr-88	540	Muscle	2	
	Cs-138	11,000	Red marrow	2	
200 Area	Cs-137	.05	Red marrow	<0.1	0.3
	Pu-239	.0004	Pulmonary	<0.1	
300-400 Areas	Kr-88	450	Pulmonary	1	30
			Bone[b]	2	
Idaho National	H-3	400	Pulmonary	<0.1	0.5
Engineering	Ar-41	2,500	Bone[b]	<0.1	
Laboratory	Kr-85	59,000	Thyroid	0.12	
	I-131	0.055	Muscle	<0.1	
			Red marrow	<0.1	
Lawrence Livermore	H-3	2,600	Red marrow	1	30
National	N-13	170	Stomach	2	
Laboratory	O-15	170	Kidneys	1	
Los Alamos	H-3	1,100	Bone[b]	11	200
National	C-11	130,000	Muscle	9	
Laboratory	N-13	25,000	Red marrow	11	
(12 Technical	O-15	200,000	Spleen	10	
Areas)	Ar-41	1,400			
Technical	H-3	6,100	Bone[b]	0.5	10
Area 33			Muscle	0.7	
			Red marrow	0.7	
			Spleen	0.7	
Oak Ridge	H-3	11,000	Pulmonary	50[d]	40
Reservation	Kr-85	6,600	Bone[b]	8	
	I-131	0.6	Thyroid	9	
	Xe-133	32,000	Kidneys	5	
	U-234	0.12	Lower large intestine	5	

See footnotes at end of table.

Table 2-A. Summary of dose rates and risks to nearby individuals for facilities with the largest emissions (Continued)

	Principal emissions		Maximum individual		
Facility	Radionuclide	Quantity (Ci/y)	Principal organ	Dose rate (mrem/y)	Risk(a) (x 10^{-6})
Paducah Gaseous Diffusion Plant	Tc-99	0.006	Pulmonary	5(e)	20
	U-234	0.01	Bone(b)	7	
	U-238	0.04	Thyroid	0.2	
			Kidneys	4	
Portsmouth Gaseous Diffusion Plant	Tc-99	0.1	Pulmonary	7(e)	30
	Th-234	0.06	Bone(b)	11	
	U-234	0.09	Thyroid	2	
			Kidneys	5	
Rocky Flats Plant	H-3	0.43	Pulmonary	<0.1	0.04
	U-234/5/8	0.00003	Bone(b)	<0.1	
	Pu-239/40	0.000008	Red marrow	<0.1	
Savannah River Plant	H-3	350,000	Bone(b)	2	40
	Ar-41	62,000	Thyroid	5	
	Kr-85	840,000	Stomach	2	
	Kr-88	1,500			
	Xe-133	3,900			
	I-131	0.05			
	I-129	0.16			

(a) Off-site location at point of highest dose equivalent.

(b) Endosteal cells.

(c) Lung clearance class for uranium: one-third D, one-third W, one-third Y.

(d) Lung clearance class for uranium: all uranium-238 and one-half uranium-234, Y; one-half uranium-234, W.

(e) Lung clearance class for uranium: all W.

Table 2-B. Summary of dose rates and risks to the regional population for facilities with largest emissions

Facility	Principal emissions		Regional population		
	Radionuclide	Quantity (Ci/y)	Principal organ	Dose rate (pers-rem/y)	Fatal cancers/year of operation
Argonne National Laboratory	Ar-41	0.4	Pulmonary	<0.1	<0.001
	Kr-85	6.7	Bone(a)	<0.1	
			Muscle	<0.1	
			Red marrow	<0.1	
Brookhaven National Laboratory	H-3	660	Pulmonary	3	<0.001
	O-15	36,000	Bone(a)	3	
	Ar-41	170	Muscle	3	
	Xe-127	2	Red marrow	3	
Feed Materials Production Center	U-234	0.11	Pulmonary	440(b)	0.02
	U-238	0.11	Bone(a)	114	
			Red Marrow	8	
			Kidneys	56	
Fermi National Accelerator Laboratory	H-3	0.4	Bone(a)	1	<0.001
	C-11	1,500	Muscle	1	
			Red marrow	1	
Hanford Reservation 100 Area, 200 Area, and 300-400 Areas	H-3	18	Pulmonary	11	0.003
	Ar-41	65,000	Bone(a)	13	
	Kr-88	990	Muscle	10	
	Cs-138	11,000	Red marrow	11	
Idaho National Engineering Laboratory	H-3	400	Bone(a)	0.3	<0.001
	Ar-41	2,500	Thyroid	5.5	
	Kr-85	59,000	Red marrow	0.2	
	I-131	0.055			
Lawrence Livermore National Laboratory	H-3	2,600	Stomach	7	0.002
	N-13	170	Kidneys	6	
	O-15	170			
Los Alamos National Laboratory (12 Technical Areas) and Technical Area 33	H-3	7,200	Bone(a)	63	0.01
	C-11	130,000	Muscle	53	
	N-13	25,000	Red marrow	61	
	O-15	200,000	Spleen	57	
	Ar-41	1,400			

See footnotes at end of table.

Table 2-B. Summary of dose rates and risks to the regional population for facilities with largest emissions (Continued)

Facility	Principal emissions		Regional population		
	Radionuclide	Quantity (Ci/y)	Principal organ	Dose rate (pers-rem/y)	Fatal cancers/year of operation
Oak Ridge Reservation	H-3	11,000	Pulmonary	212(c)	0.01
	Kr-85	6,600	Bone(a)	22	
	I-131	0.6	Thyroid	15	
	Xe-133	32,000	Kidneys	15	
	U-234	0.12	Lower large intestine	13	
Paducah Gaseous Diffusion Plant	Tc-99	0.006	Pulmonary	3.4(d)	<0.0001
	U-234	0.01	Bone(a)	13	
	U-238	0.04	Thyroid	0.4	
Portsmouth Gaseous Diffusion Plant	Tc-99	0.1	Pulmonary	11(d)	<0.001
	Th-234	0.06	Bone(a)	35	
	U-234	0.09	Thyroid	8	
			Kidneys	17	
Rocky Flats	H-3	0.4	Pulmonary	0.1	<0.001
	U-234/5/8	0.00003	Bone(a)	0.2	
	Pu-239/240	0.000008	Red marrow	0.01	
Savannah River Plant	H-3	350,000	Pulmonary	98	0.03
	Ar-41	62,000	Thyroid	120	
	Kr-85	840,000	Stomach	110	
	Kr-88	1,500			
	Xe-133	3,900			
	I-131	0.05			
	I-129	0.16			

(a) Endosteal cells.

(b) Lung clearance class for uranium: one-third D, one-third W, one-third Y.

(c) Lung clearance class for uranium: all uranium-238 and one-half uranium-234, Y; one-half uranium-234, W.

(d) Lung clearance class for uranium: all W.

Table 2-C. Summary of individual dose rates and risks to nearby individuals for facilities with small health impact

Facility	Principal organ	Dose rate (mrem/y)	Risk[a] (x 10^{-6})
Ames Laboratory	All organs	0.001	0.02
Battelle-Columbus Laboratory	Bone[b]	0.008	0.04
Bettis Atomic Power Laboratory	Pulmonary	0.004	0.02
Knolls Atomic Power Lab. (Kesselring Site)	Bone[b]	0.08	1
Knolls Atomic Power Lab. (Knolls Site)	(c)	(c)	(c)
Knolls Atomic Power Lab. (Windsor Site)	Bone[b]	0.003	0.04
Lawrence Berkeley Laboratory	Thyroid	1.6	10
Mound Facility	Bone[b]	0.2	4
Nevada Test Site	Bone[b]	0.002	0.03
Pantex Plant	Pulmonary	0.005	0.01
Pinellas Plant	Lower large intestine	0.4	5
Rockwell International Corp.	Bone[b]	0.00004	0.00007
Sandia Laboratories	Spleen	0.0009	0.02
Shippingport Atomic Power Station	All organs	0.0003	0.005
Stanford Linear Accelerator Center	Bone[b]	0.006	0.1

(a)Off-site location at point of highest dose equivalent.
(b)Endosteal cells.
(c)Kesselring and Knolls sites were assessed as a single combined site.

Table 2-D. Summary of dose rates and risks to the regional population for facilities with small health impact

Facility	Principal organ	Dose rate (pers-rem/y)	Fatal cancers/year of operation[a]
Ames Laboratory	Average all organs	0.005	< 0.0001
Battelle-Columbus Laboratory	Bone[b]	0.01	< 0.0001
Bettis Atomic Power Laboratory	Average all organs	0.01	< 0.0001
Knolls Atomic Power Lab. (Kesselring Site)	Average all organs	0.1	< 0.0001
Knolls Atomic Power Lab. (Knolls Site)	(c)	(c)	(c)
Knolls Atomic Power Lab. (Windsor Site)	Average all organs	0.002	< 0.0001
Lawrence Berkeley Laboratory	Average all organs	0.7	0.0002
Mound Facility	Average all organs	8.9	0.003
Nevada Test Site	Average all organs	0.001	< 0.0001
Pantex Plant	Average all organs	0.0008	< 0.0001
Pinellas Plant	Average all organs	0.9	0.0003
Rockwell International Corp.	Average all organs	0.0001	< 0.0001
Sandia Laboratories	Average all organs	0.003	< 0.0001
Shippingport Atomic Power Station	Average all organs	0.005	< 0.0001
Stanford Linear Accelerator Center	Bone[b]	0.04	< 0.0001

---

[a] Fatal cancers committed per year of operation of the facility.
[b] Endosteal cells.
[c] Kesselring and Knolls sites were assessed as a single combined site.

2.1 Argonne National Laboratory; Argonne, Illinois

2.1.1 General Description

Argonne National Laboratory (ANL) occupies the central 6.88 km^2 of a 15.14 km^2 tract in DuPage County, 43 km southwest of downtown Chicago, and 39 km due west of Lake Michigan. It lies in the Des Plaines River Valley, south of Interstate Highway 55 and west of Illinois Highway 83.

Argonne is an energy research and development laboratory with several principal objectives. It conducts a broad program of research in the basic energy and related sciences (physical, chemical, material, nuclear, biomedical, and environmental) and serves as an important engineering center for the study of nuclear and nonnuclear energy sources.

A significant portion of these laboratory studies requires the use of radioactive and chemically-toxic substances.

2.1.2 Process Description

The principal nuclear facilities at the Laboratory are a 200 kW light-water cooled and moderated biological research reactor (Janus) fueled with fully-enriched uranium; one critical assembly or zero power reactor (ZPR-9), that is fueled at various times with plutonium, uranium, or a combination of the two; the Argonne Thermal Source Reactor (ATSR), a 10 kW research reactor fueled with enriched uranium; a prototype superconducting heavy ion linear accelerator; a 60-inch cyclotron; several other charged particle accelerators (principally of the Van de Graaff and Dynamitron type); a large fast neutron source (IPNS, Intense Pulsed Neutron Source) in which high energy protons strike a heavy metal target to produce the neutrons; cobalt-60 irradiation sources; chemical and metallurgical plutonium laboratories; and several hot cells and laboratories designed for work with multicurie quantities of the actinide elements. Two major facilities, a 12.5 GeV proton accelerator (ZGS, the Zero Gradient Synchrotron) and a 5 MW heavy water-enriched uranium reactor (CP-5) were not in operation during 1981 and are awaiting decontamination and decommissioning.

2.1.3. Radionuclide Emissions and Existing Control Technology

Airborne emissions from Argonne National Laboratory for 1981 are identified in Table 2.1-1. The emissions for years 1979 through 1981 are summarized in Table 2.1-2. The primary source of tritiated water vapor and argon-41 prior to September 1979 was the CP-5 reactor that was taken out of service at that time. This explains a significant reduction in air emissions as indicated in Table 2.1-1. The only significant releases originated from the JANUS Reactor and the hot cell facility in Building 212. No controls are reported for the JANUS Reactor; however, the exhaust of the hot cell facility employs both wet scrubbers and electrostatic precipitators. Calculations of health impact were based on a single release point (stack height of 61 meters) located approximately 500 meters south of the plant boundary.

2.1.4 Health Impact Assessment of Argonne National Laboratory

The estimated annual radiation dose rates from radionuclide emissions from Argonne National Laboratory are shown in Table 2.1-3. The maximum individual is located 900 meters north of the assumed release point, approximately 400 meters beyond the site boundary due to the elevation of the release point (61 meters). The primary exposure pathway is external exposure resulting from argon-41.

Risks of having fatal cancer from exposure to the radioactive emissions from this facility are identified in Table 2.1-4. The highest individual lifetime risk is 6E-10 and the risk for the regional population is 7E-7 fatal cancers each year of operation.

Table 2.1-1. Radionuclide emissions from Argonne National Laboratory, 1981

Source	Radionuclide	Emissions (Ci)
JANUS Reactor	Argon-41	3.8E-1
Hot cell exhaust	Krypton-85	6.7
	Antimony-125	1.7E-5
Chemical Engineering Laboratory	Tritium	6.9E-7

Table 2.1-2. Radionuclide emissions from Argonne National Laboratory, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Antimony-125	8.5E-5	1.5E-4	1.7E-5
Argon-41	7.1E+3	8.1E-1	3.8E-1
Tritium	6.6E+2	9.0	6.9E-7
Krypton-79	1.5E-4	7.1E-4	0
Krypton-85	9.0	5.1	6.7
Krypton-85m	1.4E-5	7.6E-5	0
Xenon-133	3.6E-5	1.4E-5	0
Xenon-135	4.7E-4	6.2E-5	0

Table 2.1-3. Radiation dose rates from radionuclide emissions from Argonne National Laboratory

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Endosteal	3.3E-5	2.6E-3
Spleen	3.3E-5	2.6E-3
Red Marrow	3.1E-5	2.5E-3
Muscle	3.1E-5	2.4E-3
Pulmonary	3.1E-5	2.5E-3
Weighted Sum	2.9E-5	2.3E-3

Table 2.1-4. Fatal cancer risks due to radionuclide emissions from Argonne National Laboratory

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
ANL	6E-10	7E-7

REFERENCES

DOE82 Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

Go82 Golchert N.W., Duffy T.L. and Sedlet J., Environmental Monitoring at Argonne National Laboratory--Annual Report for 1981 (ANL-82-12), March 1982.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, Inc., McLean, Virginia, 1979.

2.2 Brookhaven National Laboratory; Long Island, New York

2.2.1 General Description

Brookhaven National Laboratory (BNL) is a large scientific research facility located near the center of Long Island approximately 113 kilometers east of New York City. BNL was originally established as a nuclear science research center but has been expanded to include facilities for non-nuclear energy studies and environmental research. Current activities at Brookhaven deal with the transmission, use, and environmental effects of nuclear and nonnuclear energy sources; physical, chemical, and biological radiation studies; and applied nuclear studies, such as those dealing with radioisotopes.

2.2.2 Process Description

A wide variety of scientific programs are conducted at Brookhaven. The major facilities at the laboratory to carry out the research and development programs include several accelerators, reactors, and groups of laboratories. The major facilities at the laboratory that release radioactivity to the atmosphere are described briefly below.

The High-Flux Beam Reactor (HFBR) is a 40-MW, fully enriched, heavy-water-moderated, -cooled, and -reflected reactor. It provides intense neutron beams for research. The core is contained in an aluminum vessel and operated at a pressure of 14.1 kg/cm^2. The reactor, its auxiliary equipment, and its experimental facilities are housed in a welded steel hemisphere 54 meters in diameter. The reactor cover gas is helium, contaminated with air, fission products, D_2O decomposition products, D_2O vapor, and tritiated heavy water vapor (DTO). Modifications to the primary water cooling system have been made to allow the power level to be raised to 60 MW(th).

The Alternating Gradient Synchrotron (AGS) is a 33-GeV proton accelerator used for ultra-high energy particle physics research. Protons originate in a 0.75 MeV Cockcroft-Walton generator, are accelerated by a 200-MeV linear accelerator (linac) and injected into the AGS. The proton beam may be deflected to strike a target or into one of the several experimental areas.

The 200-MeV linac also serves the Brookhaven Linac Isotope Production Facility (BLIP or BLIF) and the Chemistry Linac Irradiation Facility (CLIF). The BLIP was built to utilize the excess capacity of the linac to produce significant quantities of radionuclides that can be made in no other way. The principal component of the BLIP is a 10-meter deep, 2.4-meter diameter water-filled tank, into the bottom of which the 200-MeV proton beam is directed horizontally. The targets are individually jacketed and lowered to the 20-centimeter diameter irradiation chamber through J-shaped tubes. The CLIF, which is operated in a similar way, provides convenient irradiation of targets with surplus protons from the linac or secondary neutrons generated by a converter beam stop. CLIF targets are shuttled into the beam via a pneumatic target transfer system.

The tandem Van de Graaff accelerator consists of two electrostatic accelerators capable of independent or tandem use. Maximum achievable particle energy is 30 MeV. Particles ranging from hydrogen (light) to chlorine (heavy) have been accelerated. During accelerator operation, the particle beams are magnetically directed to various targets for study of nuclear and atomic reactions.

The Brookhaven Medical Research Reactor (BMRR) is a tank-type, fully enriched, water-cooled and -moderated reactor. It operates intermittently at power levels up to 3 MW (thermal) at a pressure of 246 g/cm^2. It is an integral part of the Medical Research Center and is used for various research programs requiring irradiation facilities.

BNL has several laboratories, one of which is the Hot Laboratory Complex. The Hot Lab originally provided shielded areas for research and development work with large amounts of radioactive material. It includes three remotely operable hot cells, a large radioactive metals hot cell, and several totally sealed systems for use with alpha-emitting materials. Post-irradiation processing of BLIP targets is done in one corner of the building. Liquid wastes generated within the Hot Lab are pumped to storage tanks and evaporated to a slurry. The distillate flows to the sanitary sewer, and the slurry is packaged at the Waste Management Facility and shipped as solid waste for offsite disposal.

Additional programs involving irradiations and/or the use of radionuclides for scientific investigations are carried on at other Laboratory facilities including the Biology Department, the Chemistry Department, and the Department of Energy and Environment.

2.2.3 Radionuclide Emissions

Most of the airborne radioactive effluents at Brookhaven originate from the HFBR, BLIP, and the research Van de Graaff, with lesser contributions from the Chemistry and Medical Research Centers. Radioactive releases occurred during 1981 from the seven stacks that are identified in Table 2.2-1. The quantities discharged to the atmosphere are listed in Table 2.2-2. Tritium is the most frequently discharged contaminant, although oxygen-15 ($t_{1/2}$ = 122 sec) is discharged in greatest quantity. About 63 percent of the tritium is released from the Van de Graaff stack (S-2). The BLIP stack (S-7) contributes all of the oxygen-15, while the HFBR stack (S-3) contributes 37 percent of the tritium and all xenon-127 and unidentified beta, gamma-ray releases. Thus, only small quantities of radionuclides are released from the other four sources.

Table 2.2-1. The stacks at BNL from which radionuclides were released during 1981

Stack Number	Location	Height (m)
S-1	Chemistry Building-555	UK(a)
S-2	Van de Graaff Acc., Building-901	18
S-3	HFBR - Hot Laboratory	98
S-4	Hazardous Waste Management Area	10
S-5	MRC, Building-490	UK
S-6	MRR, Building-491	UK
S-7	BLIF, Building-931	46

(a)UK - unknown.

Table 2.2-2. Radionuclide emissions (Ci) from Brookhaven National Laboratory by stack number, 1981

Radio-nuclide	Stack Number(a)						
	S-1	S-2	S-3	S-4	S-5	S-6	S-7
Tritium	4.3	4.1E+2	2.4E+2	1.8E-1	1.1	6.6E-2	
Beryllium-7				2.6E-3			
Carbon-14				8.1E-4			
Oxygen-15							3.6E+4
Phosphorus-32					1.5E-4		
Sulfur-35				5.7E-3			
Argon-41						1.7E+2	
Iron-59				2.5E-4			
Tin-113				2.6E-4			
Iodine-125				9.9E-4			
Xenon-127			2.3				
Unid. beta, gamma			1.8E-4				

(a)See Table 2.2-1 for stack identification.

The Brookhaven site covers approximately 21.3 square kilometers. However, all airborne radioactive releases from the site, excluding those from the Hazardous Waste Management Area, are located in an area that is only slightly greater than 1 square kilometer. Because only very small quantities of radioactivity are discharged from the 10 m incinerator stack (S-4) in the Hazardous Waste Management Area (See Table 2.2-2), it was decided to assess the Brookhaven Facility as having only one airborne radioactive release point: a stack positioned approximately central to the other six effluent stacks (S-1 to S-3 and S-5 to S-7).

As discussed above, nearly all effluents are released from three stacks, S-2, S-3, and S-7, that have heights of 18 m, 98 m, and 46 m, respectively (See Table 2.2-1). To be conservative, 18 m was selected as the height of the hypothetical stack representing the point source of airborne discharge. Table 2.2-3 compares the radionuclide emissions for 1979 to 1981.

Table 2.2-3. Radionuclide emissions (Ci/y) from Brookhaven National Laboratory, 1979 to 1981

Radionuclide	1979	1980	1981
Argon-41	3.2E+2	2.6E+2	1.7E+2
Beryllium-7	NR[(a)]	NR	2.6E-3
Carbon-14	NR	NR	8.2E-4
Iodine-125	NR	NR	9.9E-4
Iron-59	NR	NR	2.5E-4
Oxygen-15	2.8E+4	2.6E+4	3.6E+4
Phosphorus-32	NR	NR	1.5E-4
Sulfur-35	NR	NR	5.7E-3
Tin-113	NR	NR	2.6E-4
Tritium	2.3E+2	5.5E+2	6.6E+2
Unidentified beta + gamma	1.7E-4	7.8E-5	1.8E-4
Xenon-127	1.0	1.6	2.3

(a) NR - none reported.

2.2.4 Health Impact Assessment of Brookhaven National Laboratory

The health impact assessment for this facility is summarized in Table 2.2-4. The assessment was based on all emissions being combined into one point source. The individual receiving the maximum exposure resided 1300 meters north-northwest from the hypothetical 18 m stack. The population within the 80 km radius assessment area is about 4.6 million.

The dose equivalents to the various organs fell within a narrow range, 0.41 to 0.56 mrem/y, with the endosteal cells and red marrow receiving the larger dose equivalents. About 94 percent of the dose was due to oxygen-15 through the air immersion pathway, and tritium contributed over 5 percent of the dose, mainly through the ingestion pathway. The collective dose equivalents to the various organs were relatively uniform, ranging from 2.9 to 3.3 person-rem/y. The exposure to the regional population was primarily due to tritium (76 percent) and oxygen-15 (22 percent).

The risk of having fatal cancer as a result of exposure to the radioactive emissions from this facility are listed in Table 2.2-5. The highest individual lifetime risk is 9E-6, while the risk within the regional population for the combined sources is 9E-4 fatal cancers each year of facility operation.

Table 2.2-4. Radiation dose rates from radionuclide emissions from Brookhaven National Laboratory

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Pulmonary	4.4E-1	3.1
Red marrow	5.4E-1	3.3
Muscle	4.7E-1	3.2
Liver	4.1E-1	3.0
Endosteal	5.6E-1	2.9
Weighted sum	4.4E-1	3.2

Table 2.2-5. Fatal cancer risks due to radionuclide emissions from Brookhaven National Laboratory

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
BNL	9E-6	9E-4

REFERENCES

DOE81 Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

Na82 Naidu J.R. and Olmer L.L., Editors, 1981 Environmental Monitoring Report, Brookhaven National Laboratory, Safety and Environmental Protection Division, April 1982.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, In., McLean, Virginia, 1979.

2.3 Fermi National Accelerator Laboratory; Batavia, Illinois

2.3.1 General Description

The Fermi National Accelerator Laboratory (FNAL) is located in the Greater Chicago area just east of Batavia, Illinois, on a 27.5 km^2 tract of land. The site is roughly 4.8 km square and is operated for the Department of Energy (DOE) by Universities Research Association. The facility is composed of three basic elements: the accelerator, experimental areas, and support facilities.

The primary purpose of FNAL is fundamental research in high energy physics. In addition, cancer patients are being treated using neutrons released by the interaction of 66 MeV protons from the second stage of the accelerator. A major program is in progress to construct, install, and operate a ring of superconducting magnets. The goal is to produce higher energy protons using less electrical power.

The surrounding area is rapidly changing from farming to residential use. There are many municipalities in the vicinity, resulting in a distinct pattern of high population concentration. Within a 3-km distance from the Laboratory boundaries, Batavia (pop. 12,169), Warrenville (pop. 7,185), and West Chicago (pop. 12,444), are located. The total population within a 80 km radius of FNAL is more than 7.5 million.

2.3.2 Process Description

The FNAL is a proton synchrotron with an original design energy of 200 GeV (billion electron volts). As a result of accelerator improvements, protons were accelerated to an energy of 500 GeV in 1976 and operation at 400 GeV is now routine.

The proton beam extracted for high energy physics from the 2-km diameter main accelerator is taken to three different experimental areas on site, the Meson, Neutrino, and Proton Areas. All three areas received proton beams for the first time in 1972. Radioactivity is produced as a result of the interaction of the accelerated protons with matter. The total number of protons accelerated in 1981 was 1.4 X 10^{19}.

2.3.3 Radionuclide Emissions and Control Technology

Radioactivation of air in measurable concentrations will occur wherever the proton beam or the spray of secondary particles resulting from its interactions with matter passes through the air. Along most proton beam lines (paths of the protons from the accelerator), the protons travel inside evacuated pipes. Thus, radioactivation of air is usually caused by secondary particles.

Radioactive gas, primarily carbon-11, was produced by interaction of secondary particles with air. Monitoring was carried out by detecting the beta particles emitted in the radioactive carbon-11 decay. A release of 1.45 kCi occurred from the labyrinth stack in the Neutrino Area during 1981.

There was also a controlled release of tritium in tritiated water evaporated as a means of disposal for the first time at Fermilab in 1981. The total quantity released to the atmosphere was 420 mCi. The release occurred from the Meson Area.

A debonding oven was placed in operation in 1979. Its purpose is to debond magnets by decomposing the epoxy adhesives at high temperatures. Most of these magnets are radioactive, having failed during accelerator operations. Thirty magnets were debonded in 1981, and the total tritium release was approximately 5 mCi. Table 2.3-1 list the activity, location, and stack heights of the FNAL airborne releases for 1981. Table 2.3-2 summarizes the airborne releases from 1979 to 1981. The primary control of airborne radioactive emissions is hold-up confinement. The accelerator is designed for high efficiency, so that proton losses will be small during acceleration, extraction, and transport to the experimental-area targets.

The accelerator, beam-transport, and target systems are all within well-shielded housings, while the beam travels in evacuated pipes, thus reducing the radioactivation of air.

2.3.4 Health Impact Assessment of Fermi Laboratories

The estimated annual radiation doses resulting from radionuclide emissions from the Fermi Laboratories are listed in Table 2.3-3. The maximum individual is located 1300 meters north of the release location. The predominant exposure pathway is that of air immersion. The dose is primarily (greater than 99%) from carbon-11.

Table 2.3-4 list the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses. The lifetime risk to the maximum individual is estimated to be 1E-5 and the total number of fatal cancers per year of operation of the Fermi Laboratory to be 3E-4.

Table 2.3-1. Radionuclide emissions from Fermi National Accelerator Laboratory, 1981

Source(a)	Radionuclide	Emissions (Ci)
Neutrino Area	Carbon-11	1.5E+3
Meson Area	Tritium	4.2E-1
Debonding oven	Tritium	5.0E-3

(a) Stack height = 10 meters.

Table 2.3-2. Radionuclide emissions from Fermi National Accelerator Laboratory, 1981 (Ci/y)

Radionuclide	1979	1980	1981
Carbon-11	4.0E+3	1.3E+3	1.5E+3
Tritium	2.8E-1	2.4E-1	4.2E-1

Table 2.3-3. Radiation dose rates from radionuclide emissions from Fermi National Accelerator Laboratory, 1981

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Red marrow	6.7E-1	1.4
Endosteal	6.9E-1	1.5
Testes	6.5E-1	1.4
Spleen	6.2E-1	1.3
Muscle	5.8E-1	1.2
Weighted Sum	5.4E-1	1.1

Table 2.3-4. Fatal cancer risks due to radionuclide emissions from Fermi National Accelerator Laboratory

Source	Lifetime risk to Maximum individual	Regional population (Fatal cancers/y of operation)
FNAL	1E-5	3E-4

REFERENCES

Da80 Dave M. J. and Charboneau R., Baseline Air Quality Study at Fermilab, ANL Report, ANL/EES-TM-110, 1980.

DOE81 Department of Energy, Environmental Monitoring Report for Fermi National Accelerator Laboratory, Annual Report for CY 1981, FERMILAB 82/22, Universities Research Association Inc., Batavia, Illinois, 1981.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, In., McLean, Virginia, 1979.

2.4 Hanford Reservation; Richland, Washington

2.4.1. General Description

The Hanford Reservation is a 1,500 square-kilometer site located 270 kilometers southeast of Seattle, 200 kilometers southwest of Spokane, Washington, and 230 kilometers east of Mt. St. Helens. The Columbia River flows through the northern edge of the Hanford site and forms part of its eastern boundary.

Facilities on the Hanford Reservation include the historic reactor facilities for plutonium production along the Columbia River in the 100 Area. The reactor fuel-processing and waste-management facilities are on a plateau about 4.3 kilometers (2.7 miles) from the river in the 200 Area. The 300 Area, just north of the city of Richland, contains the reactor fuel manufacturing facilities and research and development laboratories. The Fast Flux Test Facility (FFTF) is located in the 400 Area approximately 3.8 kilometers (2.1 miles) northwest of the 300 Area, and the WPPSS power reactor site is about 4.3 kilometers (2.7 miles) north of the 300 Area.

Privately-owned facilities located within the Hanford Reservation boundaries include the WPPSS generating station adjacent to N Reactor, the WPPSS power reactor site and office buildings, and a radioactive waste burial site. The Exxon fuel fabrication facility is located immediately adjacent to the southern boundary of the Hanford Reservation.

The facilities for these programs are located at five operational areas on the reservation (designated 100, 200 East, 200 West, 300, and 400). These facilities are operated for the Department of Energy by four prime contractors. The current contractors and their primary roles are:

- Rockwell International's Rockwell Hanford Operations (RHO): waste management and fuel processing
- Douglas United Nuclear Industries (UNI): reactor operation and fuel fabrication
- Battelle's Pacific Northwest Laboratory (PNL): research in biophysics and biomedicine and development of advanced waste management technologies
- Westinghouse Hanford Company: operation of Hanford Engineering Development Laboratory (HEDL) and advanced energy research.

2.4.2 Process Description

The Hanford Reservation was originally established in 1943 to produce plutonium for nuclear weapons. At one time, nine production reactors were in operation, including eight with once-through cooling. Between December 1964 and January 1971, all eight reactors with once-through cooling were deactivated. N-Reactor, the remaining production reactor in operation, has a closed primary cooling loop. Steam from N-Reactor operation is used to drive turbine generators that produce up to 860 million watts of electrical power in the Washington Public Power Supply System's (WPPSS) Hanford Generating Plant. By the end of 1976, N-Reactor had supplied enough steam to produce nearly 35 billion kilowatt-hours of electrical energy, which was fed to the Bonneville Power Administration grid covering the Pacific Northwest.

Presently, plutonium production has decreased and other programs have been introduced and developed. Current operations include plutonium production and fabrication, management and storage of radioactive wastes, reactor operations and fuel fabrication, energy research and development, and biophysical and biomedical research.

100 Area

The 100 Area is the location of the original nine plutonium production reactors in the northern area of the Hanford site approximately 8 to 10 kilometers from the northern site boundary and adjacent to the Columbia River. The 100 Area is approximately 45 kilometers north-northwest of Richland. Eight of the reactors have been deactivated and placed on standby. Operating facilities in the 100 Area include the N-Reactor and the 1706 Laboratory.

The N-Reactor is operated by UNI and is the only plutonium production reactor still in operation on the Hanford Reservation.

Pacific Northwest Laboratory operates the 1706 Laboratory located in the 100-K Area. The laboratory conducts studies of water quality, filtration, and corrosion in support of N-Reactor operations. Small-scale decontamination studies are also done at the laboratory.

200 Area

The 200 Area is divided into the 200 East Area and the 200 West Area. The 200 East Area is located in the center of the Hanford site, approximately 15 kilometers from the east and west site boundaries and 35 kilometers north-northwest of Richland. Activities conducted in this area include irradiated fuel processing, waste management and storage, and laboratory research. The 200 West Area is adjacent to the

200 East Area. Activities conducted in the area include waste treatment and storage, equipment decontamination, plutonium and uranium processing, and laboratory research.

The PUREX Plant, located in the 200 East Area, is the fuel reprocessing facility at Hanford. Since 1972 the PUREX Plant has been held in standby and is scheduled to resume operation no later than April 1984 and continue through the year 2000. See Section 2.16 for a discussion of the future operations of DOE facilities.

Another facility in the 200 East Area is the Critical Mass Laboratory which is operated by PNL. This laboratory is used for research on the criticality safety of plutonium in its various forms and combinations with other elements. All of the remaining facilities in the 200 East Area are used for waste treatment and storage. Included among these facilities are B-Plant, C-Plant, the AR and CR vaults, and the numerous tank farms.

Major facilities in the 200 West Area include the UO_3 plant, the Z-Plant, and the Redox Plant. Uranyl nitrate hexahydrate solution (UNH) is converted to UO_3 at the UO_3 Plant. The Z-Plant has been used to finish the processing of plutonium separated during the PUREX process. Currently, a capability to complete the processing of plutonium oxide has been added to the PUREX plant; therefore, the Z-Plant will no longer be used for this purpose. The Z-Plant presently reclaims plutonium from scrap. The Redox facility currently houses Laboratories 222-S and 219-S which conduct studies in support of B-Plant operations and waste management processes.

Support facilities in the 200 West Area include the T-Plant, used for equipment repair and decontamination projects; the Plutonium Metallurgy Laboratory, operated by BNL; facility tank farms; the 242T waste evaporator; and the laundry facility.

300 Area

The 300 Area, which is in the southeast corner of the reservation, is the site of most of the laboratory and research facilities at Hanford. This area is 8 kilometers north of Richland and adjacent to the east site boundary. The major facilities are the Hanford Engineering Development Laboratory (HEDL), the fuel fabrication facility, and the Life Sciences Laboratory.

The Hanford Engineering Development Laboratory is the major facility in the 300 Area. It consists of numerous laboratories, testing facilities, and storage areas utilized in support of the Fast Breeder Reactor (FBR) program at Hanford. These facilities are operated by Westinghouse Hanford Company for the Department of Energy.

The fuel fabrication facility is operated by UNI. It is used in the production of fuel pins for the N-Reactor. The Life Sciences Laboratory is operated by PNL; current programs include biophysical and biomedical research. Studies on the inhalation of plutonium which were formerly conducted in the 100 areas were transferred to this facility in 1975. In addition, BNL operates two laboratories that conduct research in advanced waste management techniques and metallurgical techniques. These laboratories are the Metal Fabrication Laboratory and the 3720 Laboratory.

Previous programs at Hanford generated radioactive wastes which were buried in the 300 Area. These areas are not presently in use, and radioactive wastes that are being generated by current programs are shipped to the 200 Areas for processing and disposal. No airborne effluents are released from the buried wastes.

400 Area

The 400 Area is the newest of the operational areas to be developed at Hanford. The area is approximately 9 kilometers northwest of the 300 Area and 5 kilometers from the south and east site boundary. At present, the Fast Flux Test Facility (FFTF) is in operation in the 400 Area and the Fuel Materials Examination Facility (FMEF) is under construction in the 400 Area. When these facilities are both in operation, the 400 Area will be the center for the fast breeder reactor development program at Hanford.

2.4.3 Radionuclide Emissions and Control Technology

The airborne releases at Hanford Reservation are presented in Table 2.4-1. The site is large, covering an area of 1,500 square kilometers. For the purposes of analysis, Hanford is regarded as having three point sources for emissions, each at a height of 1 m above the surface. These are located in the 100 Area, 200 Area, and the combined 300-400 Area. The release point in the 100 Area is 8 kilometers from the northern site boundary at the location of N-reactor. The 200 Area stack is 10 kilometers from the southern site boundary and is located at a point midway between 200 east and 200 west Areas. The 300-400 Area release point is 0.25 kilometers from the southern boundary.

Existing Control Technology

All particulates released from Hanford operations are less than 1 micron in size. Airborne effluents from the N Reactor constitute more than 95 percent of the releases in the 100 Area. Releases from the N-Reactor are passed through HEPA filters and activated charcoal filters, while emissions from the 1706 Laboratory are exhausted through HEPA filters only.

In the 200 Area, residual operations presently occurring at the PUREX Plant account for the majority of the plutonium released in the area. Airborne effluents from all 200 Area release points are passed through acid scrubbers, deentrainers, fiberglass filters, and HEPA filters prior to release. In addition, releases from the PUREX plant are passed through a silver nitrate reactor to remove elemental iodine. Emissions from all waste management functions in the 200 East Area account for the significant release of beta- and gamma-emitting nuclides and one-third of the plutonium emissions.

In the 200 West Area, emissions from the Z-Plant include 70 percent of the area beta-gamma releases. These releases are filtered through either multilayered sand filters or HEPA filters. In addition, 80 percent of the plutonium from the U-Plant (adjacent to the UO_3 Plant) is released untreated. Discharges of plutonium-239 from Z-Plant represent more than 80 percent of the total plutonium released in the area. All of the release points at the Z-Plant are fitted with one, two, or three HEPA filters to control particulate emissions.

In the 300 Area, the fuel fabrication facility is responsible for most of of the natural uranium discharged in the area. All discharges pass through HEPA filtration prior to release.

2.4.4 Health Impact Assessment of the Hanford Site

A separate health risk assessment was performed for each of the three sources considered at this site. Summaries of these analyses are given in Table 2.4-2 and in Table 2.4-3. The size of the regional population differs for each source (266,000 for the 100 Area, 259,000 for the 200 Area, and 199,000 for the 300-400 Area). The maximum individual in the 100 Area is 7500 m northwest of the source. For the 200 Area, the maximum individual is 16,000 m south of the release point. The maximum individual in the 300-400 Area is also south of the facility, although the distance is 2000 meters.

The lifetime fatal cancer risk to the maximum individual ranges from 3E-7 to 4E-5 or 3 in 10 million to 4 in 100,000 (see Table 2.4-3). The lowest individual risk results from exposure to emissions from the 200 Area, while the highest risk is associated with the 100 Area. The number of fatal cancers expected per year within the regional population varies from 6E-5 at the 200 Area to 2E-3 at the 100 Area.

Organs receiving the five highest dose equivalent rates from emissions from the 100 Area range from 2.2 mrem/y to the pulmonary region to 2.4 mrem/y to the endosteal and spleen cells. Argon-41 contributed 92 percent of the weighted sum organ dose equivalent and 93 percent of the fatal cancer risk.

In the 200 Area, the five organs receiving the highest dose equivalent rate ranged from 1.2E-2 mrem/y to testes to 8.4E-2 to endosteal cells. Barium-137m (from decay of cesium-137) contributed 47 percent of the weighted sum organ dose equivalent and 63 percent of the fatal cancer risk.

For the 300-400 Areas, the organ dose equivalent rate for the five highest organs ranged from 1.4 mrem/y to the thymus to 1.5 mrem/y to the endosteal cells. The radionuclide of greatest significance in the area was krypton-88 which contributed 95 percent of the weighted sum dose equivalent rate and 99 percent of the fatal cancer risk.

The pathway of greatest significance dosimetrically from the 100 Area is air immersion which contributes 2.1 of the 2.1 mrem/y weighted sum dose. For the 200 Area, the majority of the 1.7E-2 mrem/y weighted sum dose equivalent rate is divided almost equally between ground surface (8.0E-3 mrem/y) and the inhalation pathways (6.1E-3 mrem/y). For the 300-400 Area, the maximum pathway is air immersion which contributes 1.2 mrem/y of the weighted sum dose equivalent rate of 1.3 mrem/y.

Table 2.4-1. Radionuclide emissions from the Hanford Reservation, 1981

Radionuclides	Emissions (Ci/y)		
	100 Area	200 Area	300-400 Area
Argon-41	6.5E+4		
Arsenic-76	2.3E-2		
Carbon-14	3.2		4.5E-7
Barium-Lanthanum-140	1.1E-1		
Cerium-144	7.9E-2		
Cobalt-58	6.6E-3		
Cobalt-60	1.6E-2		3.3E-7
Cesium-137	8.9E-3	5.0E-2	
Cesium-138	1.1E+4		
Europium-154	1.5E-1		
Europium-155	2.5E-2		
Iron-59	2.7E-3		
Tritium	1.8E+1		
Iodine-131	9.7E-2		3.0E-4
Iodine-132	4.3		
Iodine-133	9.4E-1		
Iodine-135	1.6		
Krypton-85m	2.5E+2		
Krypton-87	2.8E+2		
Krypton-88	5.4E+2		4.5E+2
Manganese-54	2.8E-3		
Manganese-56	4.6E-1		
Sodium-24	1.2E-1		
Plutonium-239	6.4E-5	3.7E-4	2.2E-5
Ruthenium-103	3.3E-3		
Ruthenium-Rhodium-106	4.2E-3		
Strontium-89	1.5E-3		
Strontium-90	4.8E-3	3.1E-3	8.8E-5
Strontium-91	1.8E-1		
Molybdenum-Technetium-99m	2.5E-1		
Uranium-234			7.5E-5
Uranium-238			7.5E-5
Xenon-135	4.6E+2		

Table 2.4-2. Radiation dose rates from radionuclide emissions from the Hanford Reservation, 1981

Organ	Maximum individual (mrem/y)		
	100 Area	200 Area	300-400 Area
Testes		1.2E-2	
Liver		2.2E-2	
Red marrow	2.3	2.0E-2	
Endosteal	2.4	8.4E-2	1.5
Pulmonary	2.2	2.1E-2	1.4
Pancreas			1.4
Upper large intestine			1.5
Thymus			1.4
Muscle	2.2		
Spleen	2.4		
Weighted sum dose equivalent rate	2.1	1.7E-2	1.3

Organ	Regional population (person-rem/y)
Red marrow	11.1
Endosteal	13.3
Pulmonary	10.7
Upper large intestine	10.7
Muscle	10.4

Table 2.4-3. Fatal cancer risks due to radionuclide emissions from the Hanford Reservation, 1981

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
100 Area	4E-5	2E-3
200 Area	3E-7	6E-5
300-400 Area	3E-5	1E-3

REFERENCES

DOE81 Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

DOE82 Department of Energy, Summary of Annual Environmental Reports for CY 1980, DOE/EP-0038, 1982.

ERDA75 Energy Research and Development Administration, Final Environmental Impact Statement, Waste Management Operations, Hanford Reservation, Richland, Washington, ERDA-1538, UC-70, Volumes 1 and 2, Washington, D.C., 1975.

ERDA77 Energy Research and Development Administration, Final Environmental Impact Statement, High Performance Fuel Laboratory, Hanford Reservation, Richland, Washington, ERDA-1550, UC-2, 11, Washington, D.C., 1977.

Su82 Sula M. J., McCormack, Dirkes R. L., Price K. R., Eddy P. A., Environmental Survillance at Hanford for CY-81, PNL-4211, May 1982.

2.5 Idaho National Engineering Laboratory; Upper Snake River Plain

2.5.1 General Description

The Idaho National Engineering Laboratory (INEL) is a large reactor testing facility located in southeastern Idaho. INEL was established in 1949 (then called the National Reactor Testing Station) to provide an isolated station where various kinds of nuclear reactors and support facilities could be built and tested. The site encompasses 2,314 square kilometers and is situated 35 kilometers west of Idaho Falls and 37 kilometers northwest of Blackfoot. As of 1976, 51 reactors had been built, 16 of which were still operating or operational.

Current programs at INEL are conducted at various areas of the site and are managed for DOE by four contractors: EG&G Idaho, Inc; Allied Chemical Corporation; Argonne National Laboratory; and Westinghouse Electric Corporation.

EG&G Idaho, Inc., operates the Power Burst Facility located in the Special Power Excursion Reactor Test Area (SPERT); the Advanced Test Reactor and the Engineering Test Reactor, located in the Test Reactor Area (TRA); the Technical Support Facility (TSF), located in the Test Area North (TAN); and the Hot Cell located in the Auxiliary Reactor Area (ARA-1). Programs that require the use of these facilities include test irradiation services from the two operating high-flux reactors and light-water-cooled reactor safety testing and research. Allied Chemical Corporation operates the Idaho Chemical Processing Plant. One of the activities performed here is the recovery of uranium from highly enriched spent fuels. Argonne National Laboratory-West (ANL-W) operates the Experimental Breeder Reactor No. 2 and related support facilities. Westinghouse Electric Corporation operates the Naval Reactor Facility at INEL.

2.5.2 Process Description

EG&G Facilities

The Power Burst Facility (PBF) is a high-performance, water-cooled, uranium-fueled reactor, designed to operate at powers of up to 40 megawatts for time intervals up to 48 hours. The facility is used to provide operating information in support of DOE's light-water reactor safety program.

The Test Reactor Area (TRA) contains six reactors (three test reactors and three low-power reactors). Of the three test reactors, only two are operating: the Advanced Test Reactor (ATR) and the Engineering Test Reactor (ETR). The third, the Materials Testing Reactor (MTR), was placed on standby in 1970. The ATR and the ETR facilities provide research data on the performance of reactor materials and equipment components under conditions of high neutron flux. This research is in support of DOE's reactor development program. Also, the facilities at TRA have occasionally been made available to private organizations and other government agencies for research purposes.

TSF, part of TAN, is used in a support role for materials examination and repair, fabrication and assembly of the Loss of Fluid Test (LOFT) Mobile Test Assembly, and various reactor safety studies. Remote disassembly and reassembly of large radioactive components are performed in the Hot Shop Area. Activities in the Warm Shop at TSF are limited to the handling of only slightly radioactive materials.

Auxiliary Reactor Area-1 (ARA-1) is presently used for the operation of research and laboratory facilities and a Hot Cell. The Hot Cell is used to prepare test specimens for use in the various INEL reactors.

The Radioactive Waste Management Complex (RWMC) is one of the three principal waste handling facilities at INEL (the other two are the ANL-W Radioactive Scrap and Waste Facility and the Idaho Chemical Processing Plant). Waste from INEL and other DOE facilities, such as Rocky Flats, is packaged and stored at RWMC.

Allied Chemical Corporation, Idaho Chemical Processing Plant

The three major activities at the Idaho Chemical Processing Plant (ICPP) are irradiated fuel storage, fuel reprocessing, and waste calcination. Spent fuel from INEL reactors and other domestic and foreign research reactors is either stored at ICPP or converted to uranium oxide powder and shipped to Oak Ridge National Laboratory (ORNL) or Portsmouth. In addition, the ICPP contains the Waste Calcining Facility (WCF), which is used to convert high-level radioactive liquid waste to solid form.

Argonne National Laboratory-West Facilities

The Argonne National Laboratory-West (ANL-W) currently has five operational complexes: the Experimental Breeder Reactor No. 2 (EBR-II), the Transient Reactor Test Facility (TREAT), the Zero Power Plutonium Reactor (ZPPR), the Hot Fuels Examination Facility (HFEF), and the Laboratory and Office (L&O) support complex. All of these complexes provide support services for DOE's Fast Breeder Reactor (FBR) research program.

Westinghouse Electric Corporation

The Naval Reactor Facility (NRF), located 22 kilometers west and north of the ANL-W area, is operated by Westinghouse Electric Corporation. The facility serves as a testing area for prototype naval reactors and as a disassembly and inspection area for expended reactor cores. The prototype reactors are also used as training centers for naval reactor operators. Three operating reactors and the Expended Core Facility (ECF) are located in this area. These include the Large Ship Reactor (A1W), the Submarine Thermal Reactor (S1W), and the Natural Circulation Reactor (S5G).

2.5.3 Radionuclide Emissions Measurements and Control Technology

Measurements of airborne releases at INEL have been consolidated and are presented in Table 2.5-1. The majority of emissions are attributable to the operation of the ATR and the ETR in the Test Reactor Area. These releases include argon-41, a majority of reported isotopes of xenon, cesium-138, barium-139, krypton-85, krypton-85m, krypton-87, and rubidium-88. TREAT accounts for the xenon-133 emissions, and activities at ICPP are responsible for exhausting tritium and krypton-85. EBR-II releases 50 percent of the total site xenon-135 emissions.

Releases from the ETR and ATR facilities are not treated. Other facilities at INEL, however, use multiple or single HEPA filters and, occasionally, charcoal absorbers. Areas using such control technologies include ZPPR, TREAT, NRF facilities, PBF, and ARA-1.

2.5.4 Health Impact Assessment of Idaho National Engineering Laboratory

For the purpose of the dose/health effects assessment, it is assumed that all particulates released are 1 micron or less in diameter, and the entire site release is respirable. The assessment is based on all emissions being combined into one point source midway between the TRA and CPP areas at a height of 1 meter above the ground. Actual site boundary distances from the assumed point source were used in the calculations.

Radiation dose rates are given in Table 2.5-2. The individual receiving the highest weighted sum dose equivalent rate is located 19500 m north of the assumed release point. The maximum individual lifetime fatal cancer risk is 5E-7. Air immersion is the major pathway contributing to the individual dose equivalent rate (68 percent).

The estimated fatal cancer risk to the regional population per year of operation is 5E-5 (Table 2.5-3). The pathway contributing primarily to the fatal cancer risk was ingestion. The collective weighted sum dose equivalent rate is 0.38 person-rems per year.

Table 2.5-1. Radionuclide emissions from Idaho National Engineering Laboratory, 1981 (DOE81)

Radionuclide	Emissions (Ci/y)
Silver-110m	8.5E-7
Argon-41	2.5E+3
Barium-131	2.2E-9
Barium-139	1.6E+2
Barium-Lanthanum-140	3.4E-5
Beryllium-7	1.3E-5
Bromine-82	9.0E-1
Carbon-14	1.7E-1
Cerium-141	1.7E-6
Cerium-144	3.9E-4
Cobalt-57	1.6E-8
Cobalt-58	3.6E-5
Cobalt-60	2.3E-4
Cesium-134	6.0E-5
Cesium-137	8.6E-3
Cesium-138	1.7E+1
Chromium-51	2.8E-5
Europium-152	6.0E-7
Europium-154	7.7E-6
Europium-155	1.5E-6
Tritium-3	4.0E+2
Hafnium-181	1.1E-5
Iodine-129	3.7E-2
Iodine-131	5.5E-2
Iodine-133	2.0E-6
Krypton-85	5.9E+4
Krypton-85m	2.2E+2
Krypton-87	8.7E+2
Krypton-Rubidium-88	8.0E+2
Manganese-54	7.3E-6
Niobium-95	2.5E-5
Promethium-144	3.7E-4
Plutonium-238	7.4E-5
Plutonium-239	1.8E-5
Ruthenium-103	1.4E-6

Table 2.5-1. Radionuclide emissions from Idaho National Engineering Laboratory, 1981 (DOE81)

Radionuclide	Emissions (Ci/y)
Ruthenium-Rhodium-106	7.7E-2
Antimony-122	1.2E-7
Antimony-125	1.9E-1
Strontium-90	4.1E-3
Tantalum-182	1.9E-7
Tellurium-132	1.6E-7
Technetium-99m	1.0E-4
Tin-113	1.8E-7
Xenon-133	1.6E+2
Xenon-135	8.0E+2
Xenon-135m	4.2E+2
Xenon-138	2.5E+3
Zirconium-95	1.9E-6

Table 2.5-2. Radiation dose rates from radionuclide emissions from Idaho National Engineering Laboratory

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Pulmonary	3.1E-2	1.7E-1
Endosteal	3.1E-2	2.6E-1
Red marrow	2.6E-2	1.9E-1
Upper large intestine	2.5E-2	1.9E-1
Muscle	2.4E-2	1.4E-1
Thyroid	1.2E-1	5.5
Weighted dose equivalent	2.9E-2	3.8E-1

Table 2.5-3. Fatal cancer risks due to radionuclide emissions from Idaho National Engineering Laboratory

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
INEL	5E-7	5E-5

REFERENCES

DOE81 Department of Energy, Effluent Information System, 1981 Emissions Data, 1981.

DOE82a Department of Energy, Idaho Operations Office, 1981 Environmental Monitoring Program Report for Idaho National Engineering Laboratory Site IDO-12082 (81), May 1982.

DOE82b Department of Energy, Summary of Annual Environmental Reports for CY1980, DOE/EP-0038, 1982.

ERDA77a Energy Research and Development Administration, Final Environmental Impact Statement, Waste Management Operations, Idaho National Engineering Laboratory, Idaho, ERDA-1536, Washington, D.C., September 1977.

ERDA77b Energy Research and Development Administration, Environmental Monitoring at Major U.S. Energy Research and Development Administration Contractor Sites, Calendar Year 1976, Volumes 1 & 2, ERDA 77-104/1 & /2, Washington, D.C., 1977.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, In., McLean, Virginia, 1979.

2.6 Lawrence Livermore National Laboratory; Livermore, California

2.6.1 General Description

The Lawrence Livermore National Laboratory is located about 64 kilometers east of San Francisco, California, in the Livermore Valley of eastern Alameda County, approximately 5 kilometers east of the City of Livermore. The site covers an area of 2.54 km^2 and is surrounded by open agricultural areas on the north, east, west, and part of the south side. Sandia Laboratories, Livermore, is located on adjoining property to the south. Materials testing and high-explosives diagnostic work is conducted at a remote site, Site 300, located on a 27 km^2 site 16 kilometers southeast of Livermore.

In addition to its primary role of nuclear weapons research and development, Lawrence Livermore National Laboratory conducts research programs in the areas of magnetic fusion, nonnuclear energy, laser fusion, laser isotope separation and biomedical research.

2.6.2 Process Description

There are five principal facilities that release radioactivity into the air at Lawrence Livermore Laboratory.

Light Isotope Handling Facility (Building 331)

Tritium is the principal nuclide released from this facility which is involved with research and development in the area of light isotopes. There is no system employed to reduce tritium from the airborne effluents. The two stacks from this facility are monitored.

Insulated Core Transfer Accelerator (ICT) (Building 212)

The ICT accelerator is an air-insulated variable energy machine which accelerates protons and deuterons up to 500 keV. The accelerator uses tritium targets for production of 14 MeV neutrons in support of the Magnetic Fusion Energy Program. Tritium is released from the facility without treatment. The effluent is continuously monitored.

Electron Positron Linear Accelerator (LINAC) (Building 194)

Operation of the 100 MEV LINAC for neutron physics research produces activation of nitrogen, oxygen, and dust particles in the air of the facility. The activation gases, primarily oxygen-15 and nitrogen-13, are released without treatment. HEPA filters are used to reduce particulate radioactivity in the airborne effluent stream. The effluent stream is continuously monitored before release to the atmosphere from a 30-meter high stack.

Decontamination Facility (Building 419)

HEPA filters are used to reduce particulate radioactivity from exhaust air. The radioactivity in air effluents originates from various decontamination operations. Stack effluents are continuously sampled.

Solid Waste Disposal Facility (Building 612)

Radioactive solid waste packaging, holding, and shipping activities are conducted at this facility. Transfer and compacting operations of dry waste may result in particulate activity being released into the facility ventilation and process air. This air is passed through HEPA filters before release to the atmosphere. During operations the stack effluent is sampled.

2.6.3 Radionuclide Emissions

Table 2.6-1 identifies radioactive emissions from the facilities at Lawrence Livermore Laboratory in 1981. For the purpose of this analysis, the total emissions are assumed to be released from Building 194 from a 30-meter stack. Radioactive emissions for the period 1979 to 1981 are shown in Table 2.6-2.

2.6.4 Health Impact Assessment of Lawrence Livermore National Laboratory

The estimated annual radiation doses resulting from radionuclide emissions from Lawrence Livermore National Laboratory are listed in Table 2.6-3. The maximum individual is located 590 meters east-northeast of the assumed release point (Building 194). The predominant exposure pathway is ingestion and primarily from tritium. The total population within an 80-km radius of the site is 4.6 million.

Table 2.6-4 shows the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses. The lifetime risk to the maximum individual is estimated to be 3E-5 and the total number of fatal cancers per year of operation is 2E-3.

Table 2.6-1. Radionuclide emissions from Lawrence Livermore National Laboratory, 1981 (Ci/y)

Radionuclide	Building					
	331	292	212	194	419	Totals
Tritium	2.6E+3	4.4E+1	2.3E+1			2.6E+3
Nitrogen-13				1.7E+2		1.7E+2
Oxygen-15				1.7E+2		1.7E+2
Plutonium-239[a]				4.2E-6	9.0E-7	5.1E-6
Strontium-90[b]				5.5E-5	1.7E-5	7.2E-5

[a] Reported as "Unidentified Alpha."
[b] Reported as "Unidentified Beta + Gamma."

Table 2.6-2. Radionuclide emissions from the Lawrence Livermore National Laboratory, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Argon-41	3.8E+2	1.6E+2	NR
Tritium	4.5E+3	2.3E+3	2.6E+3
Nitrogen-13	5.0E+2	9.9E+2	1.7E+2
Oxygen-15	3.3E+2	6.6E+2	1.7E+2
Plutonium-239[a]	7.2E-10	NR	5.1E-6
Strontium-90[b]	6.0E-5	4.7E-5	7.2E-5

[a] Reported as "Unidentified Alpha."
[b] Reported as "Unidentified Beta + Gamma."
NR=None reported.

Table 2.6-3. Radiation dose rates from radionuclide emissions from the Lawrence Livermore National Laboratory

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lower large intestine	1.9	8.7
Upper large intestine	1.5	7.0
Stomach	1.5	6.9
Small intestine		6.0
Red marrow	1.3	
Kidneys	1.3	5.8
Weighted sum	1.3	5.7

Table 2.6-4. Fatal cancer risks due to radioactive emissions from the Lawrence Livermore National Laboratory

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
LLNL	3E-5	2E-3

REFERENCES

DOE81 Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, In., McLean, Virginia, 1979.

UCRL82 University of California, Environmental Monitoring at the Lawrence Livermore National Laboratory - 1981 Annual Report, Publication No. UCRL-50027-81, University of California, Livermore, California, 1982.

2.7 Los Alamos National Laboratory; Los Alamos, New Mexico

2.7.1 General Description

The Los Alamos National Laboratory (LANL) is a multidisciplinary facility located in north-central New Mexico. The site is about 100 kilometers north-northeast of Albuquerque and 40 kilometers northwest of Santa Fe. LANL is one of the prime research and development facilities in DOE's nuclear weapons program. In addition to national defense programs, activities at Los Alamos include research in the physical sciences, energy resources (both nuclear and nonnuclear) and applied programs, and biomedical and environmental studies. Facilities for these programs are dispersed widely over the site which is separated into a number of technical areas (TAs).

A substantial portion of LANL's reported emissions may be attributed to operations at the Meson Physics Facility (TA-53), the South Mesa Site (TA-3), the Omega Site (TA-2), and several other technical areas. Programs at these sites include the operation of an 800 MeV proton accelerator, laser and magnetic fusion activities, the operation of two research reactors--one of which is a 10-MW reactor--at the Omega site, and experiments using a tandem Van de Graaff accelerator.

2.7.2 Process Description

During 1981, effluents were released from more than 75 stacks located in 13 Technical Areas. A brief description of the activities conducted in these areas follows.

TA-2, Omega Site

Omega West Reactor, an 8 megawatt nuclear research reactor, is located here. It serves as a research tool in providing a source of neutrons for fundamental studies in nuclear physics and associated fields.

TA-3, South Mesa Site

In this main technical area of the Laboratory is the Administration Building that contains the Director's office and administrative offices and laboratories for several divisions. Other buildings house the Central Computing Facility, Personnel Administration Department offices, Materials Department, the science museum, Chemistry and Metallurgy Division, Physics Division, technical shops, cryogenics laboratories, a Van de Graaff accelerator, and cafeteria.

TA-21, DP-Site

This site has two primary research areas, DP West and DP East. DP West is concerned with tritium research. DP East is the high temperature chemistry site where studies are conducted on the chemical stability and interaction of materials at temperatures up to and exceeding 3300° C.

TA-33, HP-Site

Design and development of nuclear and other components of weapon systems are conducted here. A major tritium handling facility is located here. Laboratory and office space for Geosciences Division related to the Hot Dry Rock Geothermal Project are also here.

TA-35, Ten Site

Nuclear safeguards research and development, which is conducted here, is concerned with techniques for nondestructive detection, identification, and analysis of fissionable isotopes. Research in reactor safety and laser fusion is also done here.

TA-41, W-Site

Personnel at this site are engaged primarily in engineering design and development of nuclear components, including fabrication and evaluation of test materials for weapons. Also located here is an underground laboratory that is used for physics experiments.

TA-43, Health Research Laboratory

The Biomedical Research Group does research here in cellular radiobiology, molecular radiobiology, biophysics, mammalian radiobiology, and mammalian metabolism. A large medical library, special counters used to measure radioactivity in humans and animals, and animal quarters for dogs, mice, and monkeys are also located in this building.

TA-46, WA Site

Here applied photochemistry, which includes development of technology for laser isotope separation and laser-enhancement of chemical processes, is investigated. Solar energy research, particularly in the area of passive solar heating for residences, is done.

TA-48, Radiochemistry Site

Laboratory scientists and technicians at this site study nuclear properties of radioactive materials by using analytical and physical chemistry. Measurements of radioactive substances are made and "hot cells" are used for remote handling of radioactive materials.

TA-50, Waste Management Site

Personnel at this site have responsibility for treating and disposing of most contaminated liquid wastes received from Laboratory technical areas, for development of improved methods of waste treatment, and for containment of radioactivity removed by treatment. Radioactive waste is piped to this site for treatment from many of the technical areas.

TA-53, Meson Physics Facility

The Los Alamos Meson Physics Facility (LAMPF), a linear particle accelerator, is used to conduct research in the areas of basic physics, cancer treatment, materials studies, and isotope production.

TA-54, Waste Disposal Site

This is a disposal area for radioactive and toxic wastes.

TA-55, Plutonium Processing Facilities

Processing of plutonium and research in plutonium metallurgy are done here.

2.7.3 Radionuclide Emissions

Radioactive airborne releases at Los Alamos are summarized in Table 2.7-1. Emissions from all stacks within a Technical Area were summed, and the curie quantities of each radionuclide discharged within an Area are listed (DOE82). Emissions include various isotopes of uranium and plutonium, americium-241, and activation products (beryllium-7, carbon-11, nitrogen-13, oxygen-15, phosphorus-32, argon-41, and tritium).

The Los Alamos site covers approximately 111 square kilometers and is nestled between several residential areas. Except for TA-33, the major source of tritium, all areas that contributed radioactive airborne contaminants are grouped along and within a few kilometers of the northern site boundary. Thus, it was decided to treat all emissions as two point sources; one is tritium from TA-33, and the other consists of all the remaining effluents and is located roughly central to all among the other 12 TAs. The effluents listed in Table 2.7-1 were summed to provide the radioactive source terms for the two point sources. These quantities are listed in Table 2.7-2. All effluents are released from stacks with assumed heights of 30 meters.

The effluent control devices at LANL are determined by the type of activity conducted at the facility. Facilities in which transuranics are handled are equipped with glove boxes and hot cells and use negative pressure zonation to ensure containment of accidental releases. Exhaust streams from these facilities are passed through particulate filters (usually HEPA units, although bag filters and cyclones are also used) prior to discharge from building stacks.

Activated gases produced at facilities conducting fusion beam research are held up to allow the decay of short-lived isotopes. There are no effluent controls fitted to the test reactors at the Omega Site.

2.7.4 Health Impact Assessment of Los Alamos National Laboratory

The health risk assessment performed for this facility is summarized in Tables 2.7-3 and 2.7-4. The assessment was based on all emissions being combined into two point sources: those from the TA33 site, and those from a hypothetical stack that was considered the source for all other site emissions. The health effects are reported separately for these two emission sources. The individual receiving the maximum exposure from the TA33 source could be located 930 m southwest of the stack, while the individual receiving the maximum exposure from the combined area source could be located 2100 m south-southwest of the hypothetical stack. The population within the 80 km radius assessment area is 100,000 people.

The dose equivalents received by five organs of the maximum individual exposed to emissions from the hypothetical (combined emissions) stack were about 15 to 20 times those resulting from exposure to emissions from TA33 (see Table 2.7-3). The dose equivalents to the higher exposed individual ranged from 9 to 11 mrem/y, with the red marrow and endosteal cells receiving the largest dose equivalents. External exposure (immersion) to carbon-11 and oxygen-15 contributed over 80 percent of these dose equivalents.

The collective dose equivalents listed in Table 2.7-3 were summed for the two sources yielding a total collective dose equivalents for the regional population that ranged from a maximum of 62 person-rem/y to the endosteal cells to 51 person-rem/y to the muscle. Carbon-11, oxygen-15, and nitrogen-13 were responsible for over 95 percent of the collective dose equivalents. The principal exposure pathway to the population was immersion.

The risks of having fatal cancer as a result of exposure to the radioactive emissions from this facility are listed in Table 2.7-4. The highest individual lifetime risk is 2E-4 (20 cancers in 10^5 people), while the risk within the regional population for the combined sources is 1E-2 fatal cancers each year of facility operation.

Table 2.7-1. Radionuclide emissions (Ci) from Los Alamos National Laboratory, 1981

Radionuclide	Technical Area						
	2	3	21	33	35	41	43
Tritium		9.0E+2	1.1E+2	6.1E+3		1.3E+2	
Beryllium-7							
Carbon-11							
Nitrogen-13							
Oxygen-15							
Phosphorus-32							2.0E-5
Argon-41	3.0E+2						
Iodine-131		4.4E-5					
Uranium-235		1.8E-6	1.0E-3				
Uranium-238		1.6E-4					
Uranium-235/238		5.3E-5					
Plutonium-239			6.2E-6		2.7E-7		3.7E-7
Plutonium-238/239		4.0E-5	5.9E-6				
Americium-241			2.9E-7				
MFP		1.7E-4	2.8E-6				

Radionuclide	Technical Area					
	46	48	50	53	54	55
Tritium				6.6		
Beryllium-7				3.9E+1		
Carbon-11				1.3E+5		
Nitrogen-13				2.5E+4		
Oxygen-15				2.0E+5		
Phosphorus-32						
Argon-41				1.1E+3		
Iodine-131						
Uranium-235		2.3E-6				
Uranium-238	1.4E-5					
Uranium-235/238						
Plutonium-239		1.3E-6	1.6E-6		9.0E-9	4.9E-8
Plutonium-238/239			1.2E-7			4.8E-8
Americium-241						
MFP		1.4E-3	2.3E-5			

MFP Mixed fission products.

Table 2.7-2. Radionuclide emissions (Ci) from Los Alamos National Laboratory, 1981

Radionuclide	Technical Area 33	All other TAs[a]
Tritium	6.1E+3	1.1E+3
Berryllium-7		3.9E+1
Carbon-11		1.3E+5
Nitrogen-13		2.5E+4
Oxygen-15		2.0E+5
Phosphorus-32		2.0E-5
Argon-41		1.4E+3
Iodine-131		4.4E-5
Uranium-235		1.0E-3
Uranium-238		1.7E-4
Uranium-235, -238		5.3E-5
Plutonium-239		9.8E-6
Plutonium-238, -239		4.6E-5
Americium-241		2.9E-7
MFP		1.6E-3

[a] Technical Areas: 2, 3, 21, 35, 41, 43, 46, 48, 50, 53-55. Quantities summed from Table 2.7-1.

MFP Mixed fission products.

Table 2.7-3. Annual radiation dose rates from radionuclide emissions from the Los Alamos National Laboratory

	From TA33 Source		From all other sources	
Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)	Maximum individual (mrem/y)	Regional population (person-rem/y)
Endosteal	5.4E-1	1.4	1.1E+1	6.2E+1
Red marrow	6.8E-1	1.8	1.1E+1	5.9E+1
Testes	6.8E-1	1.8	1.0E+1	5.7E+1
Spleen	6.8E-1	1.8	9.6	5.5E+1
Muscle	6.8E-1	1.8	9.1	5.1E+1
Weighted sum	6.9E-1	1.8	8.5	4.8E+1

Table 2.7-4. Fatal cancer risks due to radioactive emissions from the Los Alamos National Laboratory

Source	Maximum individual (lifetime risk)	Regional population (total cancers/y of operation)
TA33	1E-5	5E-4
All other sites	2E-4	1E-2

REFERENCES

DOE81 Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

LANL82 Los Alamos National Laboratory, Environmental Surveillance at Los Alamos During 1981, Los Alamos National Laboratory Rept., LA-9349-ENV (UC-41), April 1982.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, Inc., McLean, Virginia, 1979.

2.8 Oak Ridge Reservation; Oak Ridge, Tennessee

2.8.1 General Description

The Oak Ridge Reservation is located in northeastern Tennessee, approximately 35 kilometers west of Knoxville, Tennessee. It is in a valley between the Cumberland and Great Smokey Mountains and consists of approximately 150 square kilometers.

With the exception of the City of Oak Ridge (located on the northeastern boundary), the land within 8 kilometers of the Reservation is predominantly rural used mainly for residences, small farms and pasture. Approximately 675,000 people live within an 80 kilometer radius of the site.

2.8.2 Process Description

The three major facilities at the Oak Ridge Reservation are the Oak Ridge National Laboratory (ORNL), the Oak Ridge Gaseous Diffusion Plant (ORGDP), and the Y-12 Plant. Also located on the reservation are the Comparative Animal Research Laboratory and the Oak Ridge Associated Universities.

Oak Ridge National Laboratory

ORNL is a multipurpose research laboratory involved in basic and applied research in all areas related to energy. These research facilities consist of nuclear reactors, chemical pilot plants, research laboratories and support facilities.

The central radioactive gas disposal facilities release tritium, iodine-131, and krypton and xenon from radioisotope separations, reactor operations, and laboratory procedures. The gases undergo HEPA filtration at their source prior to discharge. The stack is constantly monitored and sampled.

The stack servicing the High Flux Isotope Reactor and the Transuranic Processing Plant releases fission product gases resulting from the chemical separation of curium and californium and from reactor operations. Process effluent gases undergo HEPA filtration.

Isotope separations and chemistry laboratory operations are the principal source of effluents. Uranium and plutonium are present in airborne effluent from the electromagnetic isotope separations facility. There are 14 exhaust points from this facility. All effluents are exhausted through one or two stages of HEPA filtration. Oil traps are also used.

A tritium target fabrication building releases small amounts of tritium from target preparation operations.

HEPA filters are used to reduce particulate activity from the transuranic research and the metal and ceramics laboratories. The effluents are monitored for alpha activity.

Oak Ridge Gaseous Diffusion Plant

The Oak Ridge Gaseous Diffusion Plant, a complex of production, research, development and support facilities, has the primary function to enrich uranium hexafluoride (UF_6) in the uranium-235 isotope.

The principal sources of release from ORGDP are the drum dryers in the decontamination facilities, which are in the uranium system, and the purging of light contaminants from the purge cascade. During 1977 the old purge cascade which used sodium fluoride and alumina traps to reduce emissions was replaced by a new purge cascade vent which has a KOH gas scrubber in the emission system.

Y-12 Plant

The Oak Ridge Y-12 Plant has four primary responsibilities: (1) production of nuclear weapons components, (2) fabrication support for weapons design, (3) support for the Oak Ridge National Laboratory, and (4) support and assistance to other government agencies. The Y-12 Plant conducts activities which include production of lithium compounds, recovery of enriched uranium from scrap material, and fabrication of uranium into finished parts and assemblies. Fabrications operations include vacuum casting, arc melting, powder compaction, rolling, forming, heat treating, machining, inspection, and testing. Many of these procedures release particulate activity into the room exhaust air. Laboratory and room air exhaust systems are equipped with filtration systems which may include prefilters, HEPA filters, or bag filters.

Oak Ridge Associated Universities

The Oak Ridge Associated Universities (ORAU) conduct research in areas such as biological chemistry, immunology, nuclear medicine, and radiochemistry. Radionuclides are handled in encapsulated or liquid form and the potential for producing gaseous effluents is very small.

2.8.3 Radionuclide Emissions

The principal radioactive atmospheric emissions are uranium-234 and uranium-238 (depleted) from the Y-12 Plant and tritium, krypton-85, and xenon-133 from the Oak Ridge National Laboratory. Table 2.8-1 summarizes the radioactive airborne emissions from the Oak Ridge facilities for 1981. For this analysis the total radioactive emissions are assumed to be released from a vent 10 meters in height at the Y-12 plant. One-half the uranium-234 is assumed to be Class Y and one-half Class W; all uranium-238 is assumed to be Class Y. Table 2.8-2 compares the radioactive emissions from Oak Ridge for the years 1979-1981.

Table 2.8-1. Radionuclide emissions from Oak Ridge Reservation (Ci/y)

Radionuclide	ORAU	ORGDP	ORNL	Y-12	1981 Total
Carbon-14	1.2E-3	-	-	-	1.2E-3
Tritium	5.2E-3	-	1.1E+4	-	1.1E+4
Iodine-125	2.5E-4	-	-	-	2.5E-4
Iodine-131	2.0E-4	-	6.0E-1		6.0E-1
Krypton-85	-	2.5E+1	6.6E+3	-	6.6E+3
Plutonium-239(a)	-	-	7.8E-8	-	7.8E-8
Technetium-99	-	3.6E-2	-	-	3.6E-2
Uranium-234	-	3.7E-3	-	1.2E-1	1.2E-1
Uranium-235	-	1.2E-4	-	-	1.2E-4
Uranium-236	-	2.4E-5	-	-	2.4E-5
Uranium-238	-	8.1E-4	-	4.0E-2(b)	4.0E-2(b)
Xenon-133	2.0E-3	-	3.2E+4	-	3.2E+4

(a)Reported as "Unidentified Alpha."
(b)Preliminary estimate.

ORAU Oak Ridge Associated Universities.
ORGDP Oak Ridge Gaseous Diffusion Plant.
ORNL Oak Ridge National Laboratory.

Table 2.8-2. Radionuclide emissions from the Oak Ridge Reservation, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Carbon-14	2.6E-4	1.6E-4	1.2E-3
Tritium	5.1E+3	1.5E+4	1.1E+4
Iodine-125	-	2.9E-4	2.5E-4
Iodine-131	3.0E-1	2.3E-1	6.0E-1
Krypton-85	1.1E+4	8.8E+3	6.6E+3
Plutonium-239(a)	4.8E-6	4.9E-6	7.8E-8
Technecium-99	1.4	8.8E-1	3.6E-2
Uranium-234	1.1E-1	1.9E-1	1.2E-1
Uranium-235	1.4E-3	8.3E-4	1.2E-4
Uranium-236	2.1E-4	1.2E-4	2.4E-5
Uranium-238	7.0E-3	4.1E-3	4.0E-2(b)
Xenon-133	5.1E+4	4.2E+4	3.2E+4

(a)Reported as "Unidentified Alpha".
(b)Preliminary estimate.

2.8.4 Health Impact Assessment of Oak Ridge Reservation

The estimated annual radiation doses resulting from radionuclide emissions from the Oak Ridge Reservation are listed in Table 2.8-3. The maximum individual is located 980 meters north of the assumed release point location at the Y-12 plant. The predominant exposure pathway is inhalation. The doses are primarily due to uranium-234 and tritium.

Table 2.8-4 lists the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses. The lifetime risk to the maximum individual is estimated to be 4E-5 and the total number of fatal cancers per year of operation to be 1E-2.

Table 2.8-3. Radiation dose rates from radionuclide emissions from the Oak Ridge Reservation

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Pulmonary	49.8	212
Thyroid	9.3	15
Endosteal	7.6	22
Kidney	5.4	15
Lower large intestine	4.9	13
Weighted sum	17.3	69.6

Table 2.8-4. Fatal cancer risks due to radionuclide emissions from the Oak Ridge Reservation

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Oak Ridge Reservation	4E-5	1E-2

REFERENCES

DOE81 Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

EPA79 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, EPA 520/7-79-006, Environmental Protection Agency, Washington, D.C., 1979.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, Inc., McLean, Virginia, 1981.

UC82 Union Carbide Corporation, Environmental Monitoring Report, United States Department of Energy Oak Ridge Facilities, Calendar Year 1981, Report No. Y/UB-16, Union Carbide Corporation, Oak Ridge, Tennessee, 1982.

2.9 Paducah Gaseous Diffusion Plant; Paducah, Kentucky

2.9.1 General Description

The Paducah Gaseous Diffusion Plant (PGDP) is a uranium enrichment cascade plant with a uranium hexafluoride (UF_6) manufacturing plant and various other support facilities (UC82). The plant is located in McCracken County, Kentucky, about 6 kilometers south of the Ohio River and 32 kilometers east of the confluence of the Ohio and Mississippi Rivers. The Paducah uranium enrichment cascade consists of 1812 stages housed in five buildings with a total ground coverage of about 0.3 km^2. Including support facilities, the plant has a total complement of about 30 permanent buildings.

Except for the large raw water treatment plant, all buildings are within a 3 km^2 fenced area. A buffer area of at least 365 meters in depth exists on all sides of the fenced area. Beyond the DOE-owned buffer is an extensive wildlife management area leased or deeded to the Commonwealth of Kentucky. There are no residences within 900 meters of any of the process buildings. The nearest incorporated towns are Metropolis, Illinois, located 8 kilometers to the northeast; and LaCenter, Kentucky, located 18 kilometers southwest. Paducah, Kentucky, a city of 35,000, is located 19 kilometers east of the plant. The population within a 80 km radius is 450,000.

2.9.2 Process Description

The primary plant, the diffusion cascade, contains a physical process in which UF_6 is fed into the system, pumped through the diffusion stages, and eventually is removed as UF_6. The product is enriched in the fissionable uranium-235 isotope and the "tails" are withdrawn at the bottom as UF_6 depleted in uranium-235. The process pumps require electric power, lubrication, and air for cooling. The compressed gases are cooled by heat exchange fluid which is, in turn, cooled by recirculating cooling water.

All the stages in the enrichment cascade are contained within five buildings. The prime source of emissions is from the purge cascade which is used for removal of light contaminants from the process stream. These contaminants, which consist of isotopes of uranium and technetium-99, are released from the diffusion cascade building stack which is sampled regularly.

The manufacturing building of Feed Plant uses hydrogen, anhydrous hydrogen fluoride (HF), and uranium oxide (UO_3) to produce the UF_6 that is fed into the diffusion cascade. Gaseous emissions, from fluorination operations of UF_4 to UF_6, are passed through a series of waste treatment systems that include cold traps, fluid bed absorbers and sintered metal filters. HEPA and bag filters are also used to treat other emissions from the Feed Plant.

The Uranium Recovery and Chemical Processing Facility conducts operations that involve pulverizing and screening of uranium salts. Here bag filters are used to reduce airborne emissions.

At the Metals Plant, depleted UF_6 from the Cascade is reacted with HF to convert it to UF_4 which is more easily stored.

2.9.3 Radionuclide Emissions

Radioactive material emissions are from two discharge points, C-310 stack and vent C-400 (Table 2.9-1) (DOE81). Releases for 1981 have increased when compared to the average for 1979-1981, except for technetium which has decreased (Table 2.9-2). All releases were assumed to be at ground level from vent C-400 (for calculation purposes). Releases for 1982 from the C-400 stack are expected to be an order of magnitude smaller due to recent improvements in emission controls. Also a new 200-ft stack will be used for releases from the former C-310 stack. All uranium emissions are assumed to be Class W.

Table 2.9-1. Radionuclide emissions from the Paducah Plant (Ci/y)

Radionuclide	C-310	C-400	Total 1981
Uranium-234	5.5E-4	1.0E-2	1.0E-2
Uranium-235	2.9E-5	5.0E-4	5.3E-4
Uranium-236	3.6E-7	3.0E-5	3.0E-5
Uranium-238	4.7E-4	3.9E-2	3.9E-2
Technetium-99	6.1E-3	-	6.1E-3

Table 2.9-2. Radionuclide emissions from the Paducah Plant, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Technetium-99	6.1E-2	5.3E-2	6.1E-3
Uranium-234	2.7E-3	6.5E-4	1.1E-2
Uranium-235	1.7E-4	3.5E-5	5.3E-4
Uranium-236	3.9E-5	4.2E-7	3.0E-5
Uranium-238	7.7E-3	5.5E-4	4.0E-2

2.9.4 Health Impact Assessment of Paducah Plant

The estimated annual radiation dose from plant emissions are listed in Table 2.9-3. The maximum individual is located 1100 meters north of the release location. The predominant exposure pathway is that of inhalation. The annual radiation dose is primarily from uranium-234 and uranium-238.

Table 2.9-4 list the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses. The lifetime risk to the maximum individual is estimated to be 2E-5 and the total number of fatal cancers per year of operation to be 2E-4.

Table 2.9-3. Radiation dose rates from radionuclide emissions from Paducah Plant

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Pulmonary	4.7	3.4
Lower large intestine	1.2E-1	2.4E-1
Endosteal	7.1	1.3E+1
Thyroid	2.0E-1	4.3E-1
Kidney	3.6	6.7
Red marrow	5.1E-1	9.3E-1
Weighted sum	1.7	1.5

Table 2.9-4. Fatal cancer risks due to radioactive emissions from Paducah Plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Paducah Plant	2E-5	2E-4

REFERENCES

DOE81 Department of Energy, Effluent Information System, Department of Energy, Washington, DC, 1981.

UC82 Union Carbide Corporation, Environmental Monitoring Report, Department of Energy, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, May 1982.

2.10 Portsmouth Gaseous Diffusion Plant; Piketon, Ohio

2.10.1 General Description

The Portsmouth Gaseous Diffusion Plant is operated by Goodyear Atomic Corporation, a subsidiary of the Goodyear Tire and Rubber Company. Support operations include the feed and withdrawal of material from the primary process; treatment of water for both sanitary and cooling purposes; decontamination of equipment removed from the plant for maintenance or replacement; recovery of uranium from various waste materials; and treatment of sewage wastes and cooling water blowdown.

The Portsmouth Gaseous Diffusion Plant is located in sparsely populated, rural Pike County, Ohio, on a 16.2-km^2 site about 1.6 km east of the Scioto River Valley at an elevation approximately 36.6 m above the Scioto River flood plain. The terrain surrounding the plant, except for the Scioto River Flood Plain, consists of marginal farm land and densely forested hills. The Scioto River Valley is farmed extensively, particularly with grain crops.

Several small communities, such as Piketon, Wakefield, and Jasper, lie within a few kilometers of the plant. The nearest community with a substantial population is Piketon (population: 1700), which is approximately 8 km north of the plant on U.S. Route 23. Population centers within 50 km of the plant are Portsmouth (population: 26,000), 32 km south; Chillicothe (population: 23,000), 34 km north; Jackson (population: 7,000), 29 km east; and Waverly (population: 5,000, 11 km north. The total population of the area lying within an 80 km radius of the plant is approximately 600,000.

2.10.2 Process Description

A cold recovery system is used in the recovery of UF_6 from comparatively large volumes of purge gases collected from locations throughout the plant. The purge gases have low UF_6 concentrations with assays of less than 27 percent uranium-235. The purge gases are passed through refrigerated cold traps to freeze out UF_6 and then through NaF traps for removal of remaining traces of UF_6 prior to being discharged to the atmosphere by means of air-jet exhausters. When the traps are full they are valved to holding drums and heated to vaporize the UF_6. After assay determination, the material is fed back to the cascade at the proper location.

2.10.3 Radionuclide Emissions

The gaseous radioactive discharges for 1981 representing all cold-recovery activities for the plant are shown in Table 2.10-1. The total air emission of radioactive material has decreased for most radionuclides from 1979 to 1981. The most significant release point for 1981 appears to be X326 Top Purge Vent. This release point discharged approximately 84 percent of the total plant release. This is shown in Tables 2.10-1 and 2.10-2. Uranium emissions are assumed to be Class W.

2.10.4 Health Impact Assessment of Portsmouth Plant

The estimated annual radiation doses resulting from emissions at the Portsmouth Plant are listed in Table 2.10-3. The maximum individual is located 1300 meters west-northwest of the release location. The predominant exposure pathway is that of inhalation. The doses are primarily from uranium-234.

Table 2.10-4 lists the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses. The lifetime risk to the maximum individual is estimated to be 3E-5, and the total number of fatal cancers per year of operation of the Portsmouth Plant to be 8E-4.

Table 2.10-1. Atmospheric emissions of radionuclides from the Portsmouth Plant, 1981

Source/Radionuclide	Emissions (Ci/y)
Top Purge Cascade	
X326 Top Purge Vent	
Protactinium-234M	3.7E-2
Technetium-99	1.0E-1
Thorium-234	3.7E-2
Uranium-234	8.5E-2
Uranium-235	2.5E-3
Uranium-236	3.4E-5
Uranium-238	1.4E-4
X330 Cold Recovery System Vent	
Protactinium-234M	2.0E-2
Technetium-99	2.8E-3
Thorium-234	2.0E-2
Uranium-234	9.7E-4
Uranium-235	4.7E-5
Uranium-236	1.1E-6
Uranium-238	5.5E-4
X-333 Cold Recovery	
X-333 Cold Recovery System Vent	
Protactinium-234M	9.9E-4
Technetium-99	1.2E-3
Thorium-234	9.9E-4
Uranium-234	5.7E-4
Uranium-235	3.3E-5
Uranium-236	1.1E-6
Uranium-238	5.6E-4
X-744-G Oxide Sampling Facility	
Hood exhaust vent	
Protactinium-234M	1.0E-5
Thorium-234	1.0E-5
Uranium-234	4.6E-6
Uranium-235	2.3E-7
Uranium-236	4.5E-9
Uranium-238	2.4E-8

Table 2.10-2. Radionuclide emissions from the Portsmouth Plant 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Protactinium-234M	6.2E-2	4.0E-2	5.8E-2
Technetium-99	1.7E-1	2.1E-1	1.1E-1
Thorium-234	6.2E-2	4.0E-2	5.8E-2
Uranium-234	8.2E-2	2.2E-1	8.7E-2
Uranium-235	2.4E-3	6.7E-3	2.6E-3
Uranium-236	5.6E-4	1.1E-4	3.6E-5
Uranium-238	1.9E-3	1.4E-3	1.3E-3

Table 2.10-3. Radiation dose rates from radionuclide emissions from the Portsmouth Plant

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Pulmonary	7	11
Thyroid	2	8
Lower large intestine	0.6	2
Endosteal	11	35
Upper large intestine	0.2	0.8
Kidney	5	17
Red marrow	0.8	3
Weighted sum	3	5

Table 2.10-4. Fatal cancer risks due to radioactive emissions from the Portsmouth Plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Portsmouth Plant	3E-5	8E-4

REFERENCES

DOE81 Department of Energy Effluent Information System, EPA Report, Department of Energy, Washington, DC, 1981.

EPA79 Environmental Protection Agency, Radiological Impact Caused by Emission of Radionuclides into Air in the United States, (Preliminary Report), EPA 520/7-79-006, Washingon, D.C., August 1979.

GA82 Goodyear Atomic Corporation, Portsmouth Gaseous Diffusion Plant Environmental Monitoring Report for Calendar Year 1981, Acox, Anderson, Hary, Klein, and Vausher, Piketon, Ohio, April 1982.

2.11 Rocky Flats Plant; Jefferson County, Colorado

2.11.1 General Description

The Rocky Flats Plant (RFP) is the prime DOE facility for the fabrication and assembly of plutonium and uranium components for nuclear weapons. The two programs at RFP that involve the handling of significant quantities of plutonium are component fabrication and assembly and plutonium scrap recovery. Fabrication operations use the metallurgical processes of casting, milling, machining, cleaning, and etching. These mechanical processes for producing weapons components generate plutonium scrap. The scrap is collected and recovered on the site.

Uranium in both the enriched and depleted forms is handled at RFP. Depleted uranium is utilized in component fabrication and is treated by many of the same metallurgical processes as plutonium. Enriched uranium is recovered from decommissioned weapons and is returned to DOE's enrichment facility at Oak Ridge for recycling.

The Rocky Flats Plant is located in Jefferson County, Colorado, approximately 26 kilometers northwest of Denver. The facilities are located within a 1.55 km^2 security area which is situated on 26.5 km^2 hectares of Federally-owned land. The site is on the eastern edge of a geological bench, with the foothills of the Rocky Mountains to the west. The area immediately surrounding the plant is primarily agricultural or undeveloped. However, about 1.8 million people reside within 80 kilometers.

2.11.2 Process Description

The processes conducted at the plant use plutonium and uranium. Plutonium is stored in closed containers in a vault with an inert atmosphere. Ingots of plutonium taken from the vault undergo metallurgical processes which include reduction rolling, blanking, forming, and heat treating. Smaller pieces of plutonium are drilled or broken to provide samples for the Analytical Laboratory and for casting operations. The formed pieces are machined into the various components which are then assembled. Assembly operations include cleaning, brazing, marking, welding, weighing, matching, sampling, heating, and monitoring. Nuclear weapons are not assembled at this plant.

Solid residue generated during plutonium-related operations is recycled through one of two plutonium recovery processes; the process selected depends on the purity and content of plutonium in the residue. Both processes result in a plutonium nitrate solution from which the metal can be extracted. The recovered plutonium is returned to the storage vault for use in foundry operations. A secondary objective of the process is the recovery of americium-241.

Rocky Flats Plant also conducts operations involving the handling of uranium. Depleted uranium-alloy scrap is consolidated and recycled at one of the foundries. The depleted uranium alloys are ore-melted into ingots for further metallurgical processing. Rocky Flats also has the capabilities to machine and assemble enriched uranium pieces. Enriched uranium components, returned because of age, are disassembled. The enriched uranium is separated and then sent to Oak Ridge, Tennessee, for recycling.

Because of its toxicity, plutonium is stored and processed under strictly controlled conditions. Much of the plutonium processing equipment is enclosed in glove boxes with an inert, nitrogen atmosphere. The glove boxes are maintained at a slight negative pressure relative to the surrounding area. This allows ventilation air to flow toward areas of greater radioactive contamination instead of away from them.

2.11.3 Radionuclide Emissions

Atmospheric emissions from the Rocky Flats Plant are listed in Table 2.11-1. Manufacturing operations at the site are reportedly responsible for 85 to 95 percent of the plutonium and uranium emissions and 55 percent of the tritium released. All particulates are assumed to be 1 micron in diameter.

Releases from the buildings at RFP are from short stacks and building vents. Given the relatively small size of the production area, the 26.5 km^2 site is considered to be a ground-level point source. For the purpose of our analysis, we have assumed that releases are from a point 2.5 kilometers from the southeastern site boundary.

Several of the release points are similar in release quantities. For comparison purpose and calculations, Building 771 - Main Plenum was selected. This point releases 54 percent of the plutonium-239, -240 and 3 percent of the uranium-233, - 234, -235. The most significant release site for uranium is Building 883, Duct B, which has approximately 19 percent of the total uranium emission.

A comparison of the source term for 1979 to 1981 is shown in Table 2.11-2.

Table 2.11-1. Atmospheric emissions of radionuclides from the Rocky Flats Plant, 1981

Source/Radionuclide	Emissions (Ci)
Plutonium Analytical Laboratory	
Tritium	2.0E-2
Plutonium-239, -240	4.4E-7
Uranium-233, -234, -238	4.1E-7
Fabrication Assembly Building	
Building 707-106 Plenum	
Tritium	3.9E-3
Plutonium-239, -240	4.7E-8
Uranium-233, -234, -238	1.6E-7
Building 707-108	
Tritium	2.5E-3
Plutonium-239, -240	5.5E-8
Uranium-233, -234, -238	9.2E-8
Building 707-105	
Tritium	4.6E-3
Plutonium-239, -240	1.6E-7
Uranium-233, -234, -238	2.8E-7
Building 707-107	
Tritium	1.4E-2
Plutonium-239, -240	5.5E-8
Uranium-233, -234, -238	2.0E-7
Building 707-101/103	
Tritium	2.6E-3
Plutonium-239, -240	5.0E-8
Uranium-233, -234, -238	3.8E-8
Building 707-102/104	
Tritium	6.4E-3
Plutonium-239, -240	1.2E-8
Uranium-233, -234, -238	1.1E-8
Manufacturing	
371 N1 + N2	
Tritium	4.3E-3
Plutonium-239, -240	5.7E-8
Uranium-233, -234, -238	8.7E-8

Table 2.11-1. Atmospheric emissions of radionuclides from the Rocky Flats Plant, 1981--continued

Source/Radionuclide	Emissions (Ci)
Manufacturing (continued)	
371 South	
Tritium	1.6E-3
Plutonium-239, -240	1.6E-8
Uranium-233, -234, -238	1.7E-8
Building 771-Main Plenum	
Tritium	8.0E-2
Plutonium-239, -240	4.5E-6
Uranium-233, -234, -238	1.0E-6
Building 771C-Main Plenum	
Tritium	4.5E-5
Plutonium-239, -240	3.8E-7
Uranium-233, -234, -238	7.4E-8
Building 771C-Room Plenum	
Plutonium-239, -240	8.9E-7
Uranium-233, -234, -238	5.6E-8
374 Waste Treatment Facility	
374 Spray Dryer	
Tritium	7.6E-4
Plutonium-239, -240	5.0E-9
Uranium-233, -234, -238	5.2E-8
Building 774-202	
Tritium	1.8E-3
Plutonium-239, -240	7.8E-8
Uranium-233, -234, -238	2.0E-8
Manufacturing Building	
Building 776-250	
Tritium	1.5E-2
Plutonium-239, -240	1.2E-7
Uranium-233, -234, -238	2.0E-7
Building 776-206	
Tritium	1.2E-1
Plutonium-239, -240	5.0E-8
Uranium-233, -234, -238	1.9E-7

Table 2.11-1. Atmospheric emissions of radionuclides from the Rocky Flats Plant, 1981--continued

Source/Radionuclide	Emissions (Ci)
Manufacturing Building (continued)	
Building 776-201/203	
Tritium	8.4E-4
Plutonium-239, -240	3.1E-9
Uranium-233, -234, -238	1.8E-8
Building 776-205	
Tritium	3.8E-2
Plutonium-239, -240	1.0E-8
Uranium-233, -234, -238	2.8E-8
Building 776-204	
Tritium	1.5E-2
Plutonium-239, -240	1.1E-7
Uranium-233, -234, -238	5.6E-7
Building 776-251	
Tritium	1.7E-8
Plutonium-239, -240	4.8E-8
Uranium-233, -234, -238	1.7E-8
Building 776-252	
Plutonium-239, -240	2.7E-8
Uranium-233, -234, -238	1.9E-8
Building 776-202	
Plutonium-239, -240	4.1E-8
Uranium-233, -234, -238	2.9E-8
Plutonium Development Building	
Building 779-729 Plenum	
Tritium	2.1E-3
Plutonium-239, -240	3.1E-8
Uranium-233, -234, -238	1.0E-7
Building 779-782 Plenum	
Tritium	4.2E-2
Plutonium-239, -240	2.5E-7
Uranium-233, -234, -238	4.6E-7

Table 2.11-1. Atmospheric emissions of radionuclides from the Rocky Flats Plant, 1981--continued

Source/Radionuclide	Emissions (Ci)
Laundry	
Building 778 Laundry	
Plutonium-239, -240	7.4E-8
Uranium-233, -234, -238	4.5E-7
Waste Treatment Facility	
Building 374-Main	
Tritium	1.9E-2
Plutonium-239, -240	5.8E-8
Uranium-233, -234, -238	1.6E-7
Manufacturing Building	
Building 444-Ducts 2 and 3	
Uranium-233, -234, -238	9.2E-7
Building 444-Duct 1	
Uranium-233, -234, -238	1.0E-6
Building 444-Duct 5	
Uranium-233, -234, -238	2.0E-7
Building 447 Main	
Uranium-233, -234, -238	1.2E-6
Materials and Process Development Laboratory	
Building 865-East	
Uranium-233, -234, -238	1.8E-7
Building 865-West	
Uranium-233, -234, -238	7.0E-7
Manufacturing Building	
Building 881-Ducts 1, 2, 3 and 4	
Tritium	4.2E-2
Plutonium-239	3.6E-7
Uranium-233, -234, -238	2.6E-6
Building 881 (Ducts 5 and 6)	
Plutonium-239, -240	2.3E-7
Uranium-233, -234, -238	4.2E-6

Table 2.11-1. Atmospheric emissions of radionuclides from the Rocky Flats Plant, 1981--continued

Source/Radionuclide	Emissions (Ci)
Manufacturing Building (continued)	
Building 883-Duct A	
Uranium-233, -234, -238	7.0E-6
Building 883-Duct B	
Uranium-233, -234, -238	5.8E-6
Nuclear Safety Facility	
Building 886-875	
Plutonium-239, -240	1.2E-8
Uranium-233, -234, -238	2.3E-7
Equipment Decontamination Building	
Building 889-Main	
Plutonium-239, -240	1.5E-8
Uranium-233, -234, -238	8.8E-7
Assembly Building	
Building 991-985	
Plutonium-239, -240	8.8E-9
Uranium-233, -234, -238	1.6E-7
991 Main	
Plutonium-239, -240	3.2E-8
Uranium-233, -234, -238	8.2E-8

Table 2.11-2. Radionuclide emissions from the Rocky Flats Plant 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Tritium	8.0E-1	7.8E-1	4.3E-1
Plutonium-239, 240	5.4E-6	1.2E-5	7.8E-6
Uranium-234	9.0E-6		
Uranium-238	2.5E-5		
Uranium-234, 235, and 238			3.0E-5
Uranium-233, 234		1.5E-5	
Uranium-238		1.4E-5	

2.11.4 Health Impact Assessment of Rocky Flats Plant

The estimated annual radiation doses resulting from radionuclide emission from the Rocky Flats Plant are listed in Table 2.11-3. The maximum individual is located 2260 meters north northwest of the release location. The predominant exposure pathway is that of inhalation. The doses are primarily from uranium-233, -234, -238 (70 percent); and plutonium-239 and -240 (30 percent).

Table 2.11-4 lists the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses. The lifetime risk to the maximum individual is estimated to be 4E-8 and the total number of fatal cancers per year of operation of the Rocky Flats Plant to be 6E-6.

Table 2.11-3. Radiation dose rates from radionuclide emissions from the Rocky Flats Plant

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Endosteal	1.5E-4	1.6E-1
Pulmonary	1.2E-2	1.3E-1
Liver	2.8E-3	2.9E-2
Red Marrow	1.2E-4	1.2E-2
Testes	2.6E-4	2.5E-3
Weighted sum	4.3E-3	

Table 2.11-4. Fatal cancer risks due to radioactive emissions from the Rocky Flats Plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Rocky Flats Plant	4E-8	6E-6

REFERENCES

DOE81	Department of Energy, Effluent Information System, Department of Energy, Washington, DC, 1981.
EPA79	Environmental Protection Agency, Radiological Impact Caused by Emission of Radionuclides into Air in the United States, (Preliminary Report), EPA 520/7-79-006, Washington, DC, August 1979.

2.12 Savannah River Plant; Aiken, South Carolina

2.12.1 General Description

The Savannah River Plant (SRP) is located in South Carolina on the Savannah River, approximately 35 kilometers southeast of Augusta, Georgia, and 150 kilometers north-northwest of Savannah, Georgia. The site occupies an area of approximately 770 square kilometers and lies within portions of Aiken, Barnwell, and Allendale Counties of South Carolina.

The facilities at SRP are used primarily in the production of plutonium and tritium, the basic materials for the fabrication of nuclear weapons. Additional activities at Savannah River include the production of special nuclear materials for medical and space applications.

2.12.2 Process Description

SRP facilities are grouped into five major areas according to their operational function in the plutonium recovery process. These areas and the major activities performed there include:

100 Area - three nuclear production reactors;

200 Area - plutonium and uranium separations, waste management;

300 Area - fuel and target fabrication;

400 Area - heavy water recovery and production;

700 Area (Savannah River Laboratory) - research and process development and pilot-scale demonstration projects.

100 Area - Nuclear Production Reactors

Of the five production reactors at SRP, only three (the P, K, and C reactors) are currently used for plutonium production. The other two, R and L, have been on standby status since 1964 and 1968, respectively. The L reactor is being upgraded and will be restarted in the fall of 1983. The impact of the L reactor restart is discussed in a later section. The three operating reactors are used to produce plutonium and tritium by the irradiation of uranium and lithium using heavy water (D_2O) as both primary coolant and neutron moderator. The heavy water is circulated in a closed system through heat exchangers.

200 Area - Separations and Waste Management Facilities

Nuclear fuel reprocessing takes place in the 200 Area, where the F and H Separations Facilities are sited. Plutonium is recovered in the

F Area, and uranium and other special nuclear materials are recovered in the H Area.

Plutonium is recovered from irradiated uranium in the F-Canyon Building using the Purex solvent-extraction process. The recovery of enriched uranium from reactor fuel and the recovery of plutonium-238 from irradiated neptunium are done in the H-Canyon Building. Both activities are performed using a procedure similar to the Purex process. Tritium is recovered from irradiated lithium/aluminum targets in three other H Area buildings.

Solid and liquid wastes from this and other DOE facilities are stored between the F and H Separation Areas.

300 Area - Fuel and Target Fabrication

Fuel and target fabrication operations are conducted in three facilities: the Alloy Extrusion Plant, the Uranium Metal Element Fabrication Plant, and the Target Extrusion Plant. Support facilities include two test reactors and the Metallurgical Laboratory.

Tubular fuel and target elements are produced at the two target extrusion plants. Coextrusion is used to clad depleted uranium (0.2 percent uranium-235) fuel and target elements with aluminum or a mixture of lithium and aluminum. A low-power reactor and a subcritical test reactor are then used to test the fabricated reactor elements for cladding defects. These elements are then shipped to the production reactors in Area 100 for irradiation.

Once the elements have been irradiated by the SRP reactors, they are inspected in the Metallurgical Laboratory. The Metallurgical Laboratory facilities are also used to test materials produced in the 300 Area.

400 Area - Heavy Water Production and Recovery

Activities in the 400 Area include both the production and the recovery of heavy water (D_2O). These operations are performed in two distillation plants and one extraction plant. The Drum Cleaning Facility and Analytical Laboratory are used as support facilities.

Heavy water is produced from river water and recovered from contaminated reactor coolant. The D_2O is then shipped to the 100 Area where it is used both as moderator and primary coolant in the production reactors.

700 Area - The Savannah River Laboratory

Research and process development work supporting the overall mission of SRP is performed at the Savannah River Laboratory (SRL). Major activities in this area include:

- fabrication of fuel element and target prototypes,
- fabrication of radioisotopic sources for medical, space, and industrial applications,
- R&D on separations processes at the pilot-scale level,
- thermal and safety studies on reactor operations, and
- applied research in the areas of physics and the environmental sciences.

2.12.3 Radionuclide Emissions and Control Technology

Annual emissions for all facilities at SRP are summarized by operational area in Table 2.12-1. Airborne releases and controls for each SRP area are described below.

100 Area - Nuclear Production Reactors

Carbon-14, argon-41, tritium, and various isotopes of krypton and xenon are the major radionuclides released from the three production reactors. Discharges range from tens of curies to hundreds of thousands of curies per year (Table 2.12-1).

All of the releases from the production reactors are from 60-meter stacks. All air exhausted from the reactor containment buildings is filtered through moisture separators, particulate filters, and carbon beds prior to release. Although these treatments are effective for particulates and radioiodine, they have little effect on the discharge of noble gases and tritium.

200 Area - Separations and Waste Management Facilities

Airborne releases from the 200 Area are from the separations facilities (the waste management facilities reportedly emit no radionuclides). Operations generating pollutants include the use of evaporators and furnaces and leakage in the process system. Major releases include tritium and activation and fission products (Table 2.12-1). Control technologies employed include either scrubbers, fiberglass filters, high-efficiency sand filters, or oxidation and moisture trapping.

300 Area - Fuel and Target Fabrication

Airborne effluents released from the 300 Area consist of natural uranium, unidentified alpha-emitters, and tritium. In 1981, there were no reported tritium or uranium releases. Off-gases from the Alloy Extrusion Plant and the Metallurgical Laboratory are passed through HEPA filters prior to discharge. Exhaust streams from the Uranium Metal Element Fabrication Plant, the Target Extrusion Plant, and the test reactors are vented directly from the buildings to ambient air without filtration. Discharges from the area are made from a variety of stacks and building vents, and release heights vary from 10 to 31 meters.

400 Area - Heavy Water Production and Recovery

Radioactive discharges from the 400 Area are composed entirely of tritium. The tritium released is from tritiated reactor coolant waters and represents less than 1 percent of the total tritium released at SRP during 1981. Releases from the 400 Area are monitored for some facilities and estimated for others. The releases are not treated prior to discharge. Discharges are from building vents and stacks; release heights range from 10 to 30 meters.

700 Area - Savannah River Laboratory

Airborne releases from SRL include cobalt-60, tritium, and iodine-131. The amount of tritium and iodine-131 released at the 700 Area accounts for less than 1 percent of the total site release of each nuclide. The cobalt-60 is the only release of this nuclide reported for the site. All discharges from processing areas are filtered through at least two stages of HEPA filtration and a multilayered sand trap before discharge from a 50-meter stack.

Summary of Radioactive Emissions at SRP

The separations facilities and the reactor areas are responsible for the majority of radioactive releases at SRP. Releases from the Savannah River Laboratory and the 300 and 400 Areas account for less than 5 percent of the total SRP releases. The production reactors release virtually all of the noble gases discharged at SRP and one-third of the tritium (see Table 2.12-1). Separations activities in the 200 Area result in the release of two-thirds of the tritium. Fuel reprocessing activities in the separations areas result in significant releases of activation products, fission products, and the transuranics. The size of all particles released is assumed to be 1 micron. Table 2.12-2 indicates the releases for 1979 to 1981.

SRP occupies a large area of 770 square kilometers. Population densities in the vicinity of the site are relatively low. For these reasons, SRP is considered to be a point source. The single stack from which releases are emitted is assumed to be 60 meters high and to be located in the center of the facility.

2.12.4 Health Impact Assessment of Savannah River Plant

The estimated annual radiation doses resulting from radionuclide emissions from the Savannah River Plant are listed in Table 2.12-3. The maximum individual is located 10,500 m east of the assumed release location (center of site). The predominant exposure pathway is that of ingestion. The doses are primarily from tritium and argon-41.

Table 2.12-4 lists the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses. The lifetime risk to the maximum individual is estimated to be 4E-5 and the total number of fatal cancers per year of operation of the Savannah River Plant to be 3E-2.

Table 2.12-1. Radionuclide emissions from the Savannah River Plant, 1981
(Ci/y)

Radionuclide	Area 100	Area 200	Area 300	Area 400	Area 700	Total
Americium-241(a)	4.4E-6	4.9E-4	3.6E-7	-	-	5.0E-4
Argon-41	6.2E+4	-	-	-	-	6.2E+4
Carbon-14	4.1E+1	2.8E+1	-	-	-	6.9E+1
Cerium-141	-	3.2E-4	-	-	-	3.2E-4
Cerium-144	-	2.6E-2	-	-	-	2.6E-2
Curium-244	-	1.6E-4	-	-	-	1.6E-4
Cobalt-60	-	-	-	-	8.9E-5	8.9E-5
Cesium-134	-	6.4E-4	-	-	-	6.4E-4
Cesium-137	-	3.1E-3	-	-	-	3.1E-3
Tritium	1.2E+5	2.3E+5	-	2.0E+3	1.5E+1	3.5E+5
Iodine-129(b)	4.5E-4	1.6E-1	-	-	5.0E-6	1.6E-1
Iodine-131	7.0E-3	3.7E-2	-	-	3.2E-3	4.7E-2
Krypton-85	-	8.4E+5	-	-	-	8.4E+5
Krypton-85m	1.3E+3	-	-	-	-	1.3E+3
Krypton-87	8.7E+2	-	-	-	-	8.7E+2
Krypton-88	1.5E+3	-	-	-	-	1.5E+3
Niobium-95	-	6.4E-2	-	-	-	6.4E-2
Plutonium-238	-	4.57E-3	-	-	-	4.6E-3
Plutonium-239(a)	4.4E-6	2.8E-3	3.6E-7	-	-	2.8E-3
Ruthenium-103	-	1.3E-2	-	-	-	1.3E-2
Ruthenium-106	-	7.8E-2	-	-	-	7.8E-2
Strontium-90(b)	4.5E-4	3.1E-3	-	-	5.0E-6	3.5E-3
Uranium-234	-	6.1E-3	-	-	-	6.1E-3
Uranium-238	-	6.1E-3	-	-	-	6.1E-3
Xenon-131m	-	6.4	-	-	-	6.4
Xenon-133	3.9E+3	-	-	-	-	3.9E+3
Xenon-135	2.5E+3	-	-	-	-	2.5E+3
Zirconium-95	-	1.7E-2	-	-	-	1.7E-2

(a)Includes one-half that activity designated as "Unidentified Alpha."
(b)Includes one-half that activity designated as "Unidentified Beta + Gamma."

Table 2.12-2. Radionuclide emissions from the Savannah River Plant, 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Americium-241(a)	4.1E-4	1.1E-3	5.0E-4
Argon-41	5.3E+4	7.0E+4	6.2E+4
Carbon-14	5.6E+1	6.6E+1	6.9E+1
Cerium-141	1.6E-4	1.1E-4	3.2E-4
Cerium-144	1.8E-2	1.6E-2	2.6E-2
Curium-244	3.9E-4	9.0E-4	1.6E-4
Cobalt-60	4.0E-4	6.2E-4	8.9E-5
Cesium-134	2.7E-2	3.8E-4	6.4E-4
Cesium-137	2.7E-3	2.6E-3	3.1E-3
Tritium	3.1E+5	2.9E+5	3.5E+5
Iodine-129(b)	1.3E-1	1.6E-1	1.6E-1
Iodine-131	8.4E-2	2.1E-2	4.7E-2
Krypton-85	4.8E+5	5.8E+5	8.4E+5
Krypton-85m	1.8E+3	3.2E+3	1.3E+3
Krypton-87	1.5E+3	2.8E+3	8.7E+2
Krypton-88	2.3E+3	4.0E+3	1.5E+3
Niobium-95	2.6E-2	1.8E-2	6.4E-2
Plutonium-238	1.4E-3	2.8E-3	4.6E-3
Plutonium-239(a)	4.5E-4	1.3E-3	2.8E-3
Ruthenium-103	4.8E-3	1.7E-3	1.3E-2
Ruthenium-106	5.5E-2	6.0E-2	7.8E-2
Strontium-90(b)	2.6E-3	3.6E-3	3.5E-3
Uranium-234	2.4E-3	4.0E-3	6.1E-3
Uranium-238	2.4E-3	4.0E-3	6.1E-3
Xenon-131m	9.1	1.9E-1	6.4
Xenon-133	5.3E+3	4.9E+3	3.9E+3
Xenon-135	4.5E+3	6.4E+3	2.5E+3
Zirconium-95	1.3E-2	1.4E-2	1.7E-2

(a) Includes one-half that activity designated as "Unidentified Alpha."

(b) Includes one-half that activity designated as "Unidentified Beta + Gamma."

Table 2.12-3. Radiation dose rates from radionuclide emissions from the Savannah River Plant

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Thyroid	4.9	1.2E+2
Lower large intestine	2.9	1.4E+2
Upper large intestine	2.5	1.1E+2
Stomach	2.4	1.1E+2
Endosteal	2.2	9.7E+1
Pulmonary	2.1	9.8E+1
Weighted sum	2.2	9.8E+1

Table 2.12-4. Fatal cancer risks due to radioactive emissions from the Savannah River Plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
SRP	4E-5	3E-2

REFERENCES

DOE81a Department of Energy, Environmental Monitoring in the Vicinity of the Savannah River Plant, Annual Report for 1981, DPSPU-82-30-1, E.I. du Pont de Nemours and Company, Aiken, South Carolina, 1981.

DOE81b Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, Inc. McLean, Virginia, 1979.

2.13 Feed Materials Production Center; Fernald, Ohio

2.13.1 General Description

The Feed Materials Production Center (FMPC), operated by the National Lead Company of Ohio, is located on 425 hectares in southwestern Ohio in Hamilton and Butler counties. The facility is 1.6 kilometers north of Fernald and 32 kilometers northwest of Cincinnati. The population within an 80 kilometer radius of FMPC is 2.6 million.

2.13.2 Process Description

The Feed Materials Production Center produces purified uranium metals, uranium rod and tubing extrusions, uranium compounds, and some thorium compounds for use by other Department of Energy (DOE) facilities. Uranium may be natural, depleted, or enriched with respect to uranium-235; the average uranium-235 content is that of natural uranium. Feed stock may be ore concentrates, recycled uranium, or various uranium compounds.

Impure feedstock is dissolved in nitric acid, and the uranium is separated by organic liquid extraction. It is then reconverted to uranyl nitrate, heated to form a trioxide powder, reduced with hydrogen to uranium dioxide, and reacted with anhydrous hydrogen fluoride to produce uranium tetrafluoride. Purified metal is produced by reacting uranium tetrafluoride with metallic magnesium in a refractory-lined vessel, remelted with scrap uranium metal, and cast into ingots. From these ingots uranium rods and tubing are extruded, cut, machined, and finally sent to other DOE facilities for fabrication into nuclear reactor fuel elements.

The facility periodically purifies small quantities of thorium through production steps similar to those outlined above for uranium. Finished products include thorium metal, thorium nitrate solution, and solid thorium compounds.

There are eight buildings at FMPC for these production activities. Exhausted air from these buildings is passed through scrubbers or cloth type bag filters prior to release to building stacks. The processes associated with each of the eight buildings are as follows:

Plant 1	Material sampling and grinding;
Plant 2	Dry feeds digestion;
Plant 4	Uranium tetrafluoride production and repackaging;
Plant 5	Metal production and slag grinding;
Plant 6	Metal machining;

Plant 8	Dumping and milling;
Plant 9	Metal production, remelting, and machining;
Pilot Plant	Uranium and thorium metal and compound production.

2.13.3 Radionuclide Emissions

Table 2.13-1 summarizes the radionuclide emissions from FMPC in 1981 for each of the eight stacks and an on-site incinerator. Only natural uranium was released during 1981; no thorium was released during the year.

Table 2.13-1. Radionuclide emissions from Feed Materials Production Center, 1981 (Ci/y)

Source	Natural uranium emissions (Ci/y)
Plant 1	3.3E-4
Plant 2	0.
Plant 4	6.26E-2
Plant 5	4.46E-2
Plant 6	0.
Plant 8	5.33E-3
Plant 9	0.
Pilot Plant	0.
Incinerator	4.15E-4
Total	0.113

2.13.4 Health Impact Assessment

For the health impact assessment, all releases were assumed to originate from a single 10-meter stack at the center of the production area. The nearest site boundary is 680 meters. Since only natural uranium was released during 1981, the assumption was made that the release consisted of one-half uranium-234 and one-half uranium-238 in equilibrium with its daughters, thorium-234 and protactinium-234m.

The estimated annual radiation doses from radionuclide emissions from FMPC are shown in Table 2.13-2. These estimates are for a regional population of 2.6 million. The maximum individual is located 810 m northeast of the release point at the site boundary. The major pathway of exposure is inhalation, and the critical organ is the pulmonary, with a dose equivalent of 88 mrem/y.

The individual lifetime risk and the number of fatal cancers per year of operation are shown in Table 2.13-3. The lifetime risk to the maximum individual is estimated to be 2E-4 and the total number of fatal cancers per year of operation is estimated to be 2E-2.

Table 2.13-2. Radiation dose rates from radionuclide emissions from the Feed Materials Production Center

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Pulmonary	88	440
Endosteal	26	114
Kidney	12	56
Lower large intestine	0.4	
Red marrow	1.8	8
Weighted sum	26	132

Table 2.13-3. Fatal cancer risks due to radionuclide emissions from the Feed Materials Production Center

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
FMPC	2E-4	2E-2

REFERENCES

DOE81 Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

ERD77 Energy Research and Development Administration, Feed Materials Production Center, Environmental Monitoring Annual Report for 1976, NLCO-1142, Bobach, M. W., et al., National Lead Company of Ohio, Cincinnati, Ohio, 1977.

EPA79 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, Preliminary Report, EPA 520/7-79-006, Environmental Protection Agency, Washington, D.C., 1979.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, Inc., McLean, Virginia, 1979.

2.14 Ames Laboratory; Ames, Iowa

2.14.1 General Description

Ames Laboratory is operated by Iowa State University for the Department of Energy. The principal facility is the Ames Laboratory Research Reactor, located 2.4 km northwest of the Iowa State University campus and 4.8 km northwest of Ames, Iowa. The site occupies 16.2 hectares in Story County.

2.14.2 Process Description

The Ames Laboratory Research Reactor (ALRR) was used until 1978 as a neutron source for the production of byproduct materials and the neutron irradiation of various materials for research. The reactor was fueled with enriched uranium, was moderated and cooled by heavy water (D_2O), and was operated continuously at 5000 watts thermal. Operation of the ALRR was terminated on December 1, 1977. Decommissioning began January 3, 1978, and was completed on October 31, 1981. Also located at the site is the waste disposal processing facility, serving both the reactor and the research laboratories located on campus.

2.14.3 Radionuclide Emissions

Prior to decommissioning, the major airborne releases were tritium and argon-41 from the ALRR. Tritium was the major radionuclide released during the 1981 decommissioning activities. Table 2.14-1 contains the release data for 1981. These releases are from the 30-meter reactor stack, located 215 meters from the nearest boundary, with an annual exhaust volume of 2.5E+14 ml. No airborne emissions have been found from the research laboratories on the main campus.

2.14.4 Health Impact Assessment of Ames Laboratory

The estimated annual radiation doses from radionuclide emissions from ALRR are listed in Table 2.14-2. These estimates are based on a regional population of 630,000. The maximum individual is located 750 meters north of the facility. The major pathway of exposure was ingestion.

Table 2.14-3 presents estimates of the maximum individual lifetime risks and the number of fatal cancers per years of operation from these doses. The lifetime risk to the maximum individual is estimated to be 2E-8 and the total number of fatal cancers per year of operation is estimated to be 1E-6.

Table 2.14-1. Radionuclide emissions from Ames Laboratory, 1981

Radionuclide	Emissions (Ci/y)
Cobalt-60	2.2E-7
Tritium	4.5
Unidentified alpha	1.6E-7
Unidentified beta + gamma	2.7E-6
Zinc-65	2.4E-7

Table 2.14-2. Radiation dose rates from radionuclide emissions from Ames Laboratory for 1981

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lower large intestine	1.4E-3	5.5E-3
Endosteal	1.1E-3	4.8E-3
Upper large intestine	1.1E-3	4.5E-3
Stomach	1.1E-3	4.4E-3
Pulmonary	9.6E-4	4.0E-3
Weighted Sum	9.6E-4	3.9E-3

Table 2.14-3. Fatal cancer risks due to radionuclide emissions from Ames Laboratory, 1981

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
ALRR Stack	2E-8	1E-6

REFERENCES

DOE81 Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

DOE82 Department of Energy, Environmental Monitoring Summary for Ames Laboratory, Calendar Year 1981, IS-4798, Milo D. Voss, Ames Laboratory, Ames, Iowa, 1982.

ERDA77 Energy Research and Development Administration, Environmental Monitoring at Ames Laboratory, Calendar Year 1976, IS - 4139, Milo D. Voss, Ames Laboratory, Ames, Iowa, 1977.

EPA79 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, Preliminary Report, EPA 520/7-79-006, Environmental Protection Agency, Washington, D.C., 1979.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, Inc., McLean, Virginia, 1979.

2.15 Battelle-Columbus Laboratory; Columbus, Ohio

2.15.1 General Description

The Battelle-Columbus Laboratory (BCL) is located in the Greater Columbus area and conducts activities for the Nuclear Regulatory Commission as well as the Department of Energy (under Contract No. W-7405-ENG-92).

BCL operates two complexes, the King Avenue Site in Columbus and the West Jefferson Site (Nuclear Sciences Area) which is located approximately 27 kilometers west of the King Avenue Laboratories.

King Avenue Site

The King Avenue Site is located on a four-hectare track which is bounded on the north by the Ohio State University intramural sports practice field, on the west by the Olentangy River and on the south and east by two- and four-family dwellings.

West Jefferson Site (Nuclear Sciences Area)

The Nuclear Sciences Area occupies a four-hectare-fenced security area on 405 hectares. A 16-kilometer radius circle whose center is at the site includes a small portion of Columbus having a population of about 60,000. The only other significant population center near the site is West Jefferson, Ohio, located about 3.2 kilometers to the southwest with a population of 5,700.

2.15.2 Process Description

King Avenue Site

The Uranium-235 Processing Facility, located on the first floor of Building 3, is the management point for all transactions involving nuclear materials at the King Avenue Site. Building 3 also houses the Melting Facility and the Power Metallurgy Laboratory.

Activities involving contract and license materials were very limited during 1981; therefore, effluent monitoring at this site was limited to liquid discharges only. There were no reported airborne releases for 1981.

West Jefferson Site (Nuclear Sciences Area)

Facilities in this area include the JN-1 Hot Cell Facility, the JN-2 Vault Facility, and the JN-4 Plutonium Laboratory which is being decontaminated. The JN-4 Plutonium Laboratory was conducting research on uranium-235/plutonium-239 nitride reactor fuel. The Nuclear Sciences Area also houses a decommissioned Research Reactor.

The JN-1 Hot Cell Facility the JN-2 Vault Facility and are presently the only facilities at the Nuclear Sciences Area where contract materials are handled.

Irradiated reactor fuel element studies are conducted at the JN-1 Hot Cell Facility, and materials accountability and storage operations are conducted at the JN-2 Vault Facility.

2.15.3 Radionuclide Emissions and Control Technology

Radionuclide emissions from the West Jefferson Site are presented in Table 2.15-1. Emissions for 1979 through 1981 are listed in Table 2.15-2. All particulates are 1 micron or less in diameter and are thus respirable. For health impact assessments, we assume Battelle Laboratories to be a point source with a stack height of 10 meters.

There were no reported airborne releases for the King Avenue Facility for 1981.

Control Technology

Radionuclide emissions at the Battelle Columbus Laboratory are first filtered at the points of operations, i.e., glove boxes, hoods, test cells, and then passed through one or two stages of HEPA filters before release. The Hot Cell Facility is equipped with a charcoal bed so radioactive gases can be routed through it when necessary.

Table 2.15-1. Radionuclide airborne emissions
Battelle Columbus, West Jefferson Site (Ci/y)

Radionuclide	JN-1	JN-2	JN-4	Total 1981
Bismuth-214	3.1E-6	-	-	3.1E-6
Cerium-141	3.1E-8	-	-	3.1E-8
Cerium-144	6.6E-7	-	-	6.6E-7
Cobalt-57	1.1E-8	-	-	1.1E-8
Cobalt-60	3.0E-7	-	-	3.0E-7
Cesium-134	2.5E-6	-	-	2.5E-6
Cesium-137	7.4E-6	-	-	7.4E-6
Europium-152	1.1E-7	-	-	1.1E-7
Potassium-40	9.0E-6	-	-	9.0E-6
Lead-212	6.3E-7	-	-	6.3E-7
Lead-214	3.1E-6	-	-	3.1E-6
Rhodium-106	1.4E-7	-	-	1.4E-7
Antimony-125	8.6E-6	-	-	8.6E-6
Uranium-235	9.8E-7	-	-	9.8E-7
Plutonium-239	-	1.4E-8	1.5E-7	1.6E-7
Unidentified Alpha	-	1.4E-8	-	1.4E-8
Unidentified Beta and Gamma	-	1.1E-7	-	1.1E-7

Table 2.15-2. Radionuclide emissions from Battelle-Columbus, West Jefferson Site (Ci/y)

Radionuclide	1979	1980	1981
Actinium-228	7.6E-7	1.5E-7	-
Americium-241	4.9E-8	-	-
Barium-133	1.7E-6	2.1E-8	-
Barium-140	1.3E-7	-	-
Bismuth-244	9.6E-7	5.6E-7	3.1E-6
Cadmium-109	5.7E-7	-	-
Cerium-134	-	4.8E-8	-
Cerium-139	2.1E-8	2.9E-8	-
Cerium-141	4.2E-8	1.4E-7	3.1E-8
Cerium-144	7.3E-7	5.6E-7	6.6E-7
Cobalt-57	1.1E-7	5.9E-8	1.1E-8
Cobalt-60	2.5E-6	8.5E-6	3.0E-7
Cesium-134	3.0E-8	-	2.5E-6
Cesium-136	3.9E-7	-	-
Cesium-137	9.8E-8	6.9E-7	7.4E-6
Chronium-51	-	3.1E-7	-
Dysprosium-159	4.0E-8	-	-
Europium-152	-	-	1.1E-7
Europium-154	1.5E-8	8.8E-11	-
Europium-155	1.8E-7	-	-
Iodine-129	5.1E-8	-	-
Iodine-131	-	8.0E-7	-
Potassium-40	-	-	9.0E-6
Krypton-85	3.9E-1	2.8E+2	-
Manganese-54	1.1E-7	-	-
Neptunium-239	-	8.9E-6	-
Lead-210	3.7E-8	-	-
Lead-212	4.1E-7	1.5E-7	6.3E-7
Lead-214	2.6E-7	2.3E-7	3.1E-6
Rhodium-101	6.7E-9	1.7E-8	-
Rhodium-106	-	-	1.4E-7
Antimony-125	5.6E-7	8.7E-5	8.6E-6
Samarium-145	2.3E-7	-	-
Tellurium-125	-	3.8E-6	-
Tantalum-182	4.4E-8	-	-
Terbium-160	1.0E-7	-	-
Thorium-228	-	1.7E-6	-

Table 2.15-2. Radionuclide emissions from Battelle-Columbus, West Jefferson Site (Ci/y) (Continued)

Radionuclide	1979	1980	1981
Thorium-234	3.6E-8	-	-
Thallium-208	3.4E-7	5.1E-8	-
Uranium-235	2.3E-8	2.4E-7	9.8E-7
Plutonium-238	1.1E-7	-	-
Plutonium-239	2.5E-7	4.4E-7	1.6E-7
Xenon-138	2.1E-7	-	-
Unidentified Alpha	1.2E-7	-	1.4E-8
Unidentified Beta and Gamma	1.9E-6	-	1.1E-7

2.15.4 Health Impact Assessment of Battelle-Columbus Laboratory

The estimated annual radiation doses resulting from radionuclide emissions from the Battelle Laboratories are listed in Table 2.15-3. The maximum individual is located 150 meters north of the release location and the predominant exposure pathway is inhalation.

Table 2.15-4 list the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses. The lifetime risk to the maximum individual is estimated to be 4E-8 and the total number of fatal cancers per year of operations of the Battelle-Columbus Laboratory is estimated to be 7E-7.

Table 2.15-3. Radiation dose rates from radionuclide emissions from Battelle-Columbus, West Jefferson Site

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Endosteal	7.7E-3	9.9E-3
Pulmonary	7.6E-3	1.0E-2
Liver	2.0E-3	2.7E-3
Spleen	9.5E-4	1.4E-3
Testes	9.4E-4	
Red marrow		2.1E-3
Weighted sum	3.1E-3	4.2E-3

Table 2.15-4. Fatal cancer risks due to radionuclide emissions from Battelle-Columbus, West Jefferson Site

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
West Jefferson Site	4E-8	7E-7

REFERENCES

DOE81a Department of Energy, Environmental Monitoring Report for Battelle Columbus Laboratories, Annual Report for CY 1981, Battelle Columbus Laboratories, Columbus, Ohio, 1981.

DOE81b Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (Unpublished), Teknekron Research Inc., McLean, Virginia, 1979.

2.16 Bettis Atomic Power Laboratory; West Mifflin, Pennsylvania

2.16.1 General Description

The Bettis Atomic Power Laboratory is sited on an 0.8 square kilometer tract in West Mifflin, Pennsylvania, approximately 12 km south of Pittsburgh. The facility designs and develops of nuclear power reactors. Currently, the most significant program at Bettis is the fabrication of the fuel assemblies used in DOE's light-water-breeder reactor program. The population within 80 kilometers of the release is 3.2 million.

2.16.2 Process Description

Bettis facilities, which include both development laboratories and fabrication facilities, are clustered in the northwest corner of the site. There is no information available which identifies the activities conducted within specific buildings at the site. Emissions data for the site are reported only in aggregate form; therefore, it is impossible to attribute releases to a specific activity.

2.16.3 Radionuclide Emissions and Existing Control Technology

Airborne emissions data for Bettis are presented in Table 2.16-1. Reported airborne releases are primarily krypton-85 with much lesser amounts of antimony-125 and iodine-131.

Gaseous effluent streams from activities at Bettis are treated with wet scrubbing and passed through charcoal absorbers and HEPA filtration units prior to release.

2.16.4 Health Impact Assessment of Bettis Atomic Power Laboratory

The entire site is treated as a ground level point source located centrally within the facility. For purposes of the dose/health effects assessment, it is assumed that all particulates released are 1 micron or less in diameter and all releases are respirable. Actual site boundary distances were used in the calculations.

Table 2.16-2 lists the estimates of the annual radiation doses resulting from radionuclide emissions. The individual (offsite) receiving the maximum dose equivalent rate is located 410 meters north of the release point. The major pathway contributing to the individual dose equivalent rate is inhalation (76 percent).

Table 2.16.3 lists the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses. The lifetime risk to the maximum individual is estimated to be 2E-8. The estimated collective fatal cancer risk per year of operation is 2E-6. Inhalation is the predominant pathway contributing to the fatal cancer risk (64 percent.

Table 2.16-1. Radionuclide emissions from Bettis Atomic Power Laboratory, 1981

Radionuclide	Emissions (Ci/y)
Tritium	3.0E-5
Iodine-129	2.5E-7
Iodine-131	8.4E-7
Krypton-85	1.6E-1
Antimony-125	5.8E-5
Unidentified alpha (assumed equally uranium-234 and uranium-238)	1.8E-6
Unidentified beta-gamma (assumed equally cesium-137, cobalt-60, and strontium-90)	1.52E-5

Table 2.16-3. Radiation dose rates from radionuclide emissions from the Bettis Atomic Power Laboratory

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Pulmonary	3.9E-3	
Thyroid	1.5E-3	
Endosteal	8.6E-4	
Red marrow	5.5E-4	
Spleen	2.6E-4	
Weighted sum	1.4E-3	1.3E-2

Table 2.16-4. Fatal cancer risks due to radioactive emissions from the Bettis Atomic Power Laboratory

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
BAPL	2E-8	2E-6

REFERENCES

BAPL82 Effluent and Environmental Monitoring Report for Calendar Year 1981, Bettis Atomic Power Laboratory, WAPD-RC/E(ESE)-576, 1982.

DOE81 Department of Energy, Effluent Information System, 1981 Emissions Data, 1981.

DOE82 Department of Energy, Summary of Annual Environmental Reports for CY1980, DOE/EP-0038, 1982.

ERDA77 Energy Research and Development Administration. Environmental Monitoring at Major U.S. Energy Research and Development Administration Contractor Sites, Calendar Year 1976, Volumes 1 & 2, ERDA 77-104/1 & /2, Washington, D.C., 1977.

TRI81 Teknekron Research, Inc. Information Base for the Evaluation and Control of Radioactive Materials to Ambient Air, 1981.

2.17 Knolls Atomic Power Laboratory; Knolls, Kesselring, and Windsor Sites; Schenectady, New York

2.17.1 General Description

The Knolls Atomic Power Laboratory (KAPL) is operated for the Department of Energy (DOE) by the General Electric Company. The facilities of KAPL are located on three separate sites: Knolls, Kesselring, and Windsor.

The primary missions at KAPL are the development of nuclear reactors and the training of operating personnel.

Knolls and Kesselring Sites

The Knolls and Kesselring sites are both located in east central New York State. The Knolls facilities are located on a 0.69 square kilometer tract about 8 kilometers east of Schenectady. The Kesselring site is about 27 kilometers north of Schenectady, and occupies an area of almost 16 square kilometers. Schenectady, Albany, and Troy to the south, and Saratoga Springs to the north-northeast are the major population centers in the vicinity. Land use in the vicinity of the two sites is typical low density residential, with numerous small truck and dairy farms. The population within 80 kilometers is 1.2 million.

Windsor Site

The Windsor site, which occupies a 0.04 square kilometer tract, is located just northwest of the town of Windsor, Connecticut. Hartford, lying 12 kilometers south, and Springfield, Massachusetts, 20 kilometers north, are the major population centers in the vicinity of the facility. Land in the immediate area (0-10 km) is a mixture of low density residential and small scale agriculture. The principal crop is shade-grown wrapper tobacco. Population within 80 kilometers of the site is 3.1 million.

2.17.2 Process Description

Facilities at the Knolls site are utilized in the development of nuclear power plants. Nuclear power plant operators are trained at the Kesselring and Windsor sites. Pressurized water reactors are located at both the Kesselring and Windsor site.

2.17.3 Radionuclide Emissions and Control Technology

The chemistry, physics, and metallurgy laboratories at the Knolls site are the only potential emitters of radionuclides to the atmosphere, while effluents from reactor operations are the only source of radioactive emissions at the Kesselring and Windsor sites.

All releases at the Knolls site are from elevated stacks (assumed height 20 meters) and all exhaust streams carrying radioactive effluents are passed through HEPA filters or activated carbon filters.

The exhaust systems of the reactors at both the Kesselring and Windsor sites are fitted with HEPA filtration systems to control particulate emissions. There are no controls for gaseous effluents. Releases at both sites are from elevated stacks.

Combined airborne emissions for 1981 from the KAPL sites are given in Table 2.17-1.

Table 2.17-1. Radionuclide emissions from Knolls Atomic Power Laboratory

Radionuclide	Emissions (Ci/y)	
	Knolls and Kesselring sites	Windsor site
Argon-41	3.8	1.0E-4
Bromine-82	3.3E-4	
Carbon-14	1.8E-1	5.7E-3
Cobalt-60	2.3E-6	4.0E-7
Cesium-137	4.0E-5	
Iodine-131	4.05E-6	
Krypton-83m	1.1E-3	2.4E-4
Krypton-85	1.4E-1	1.0E-5
Krypton-85m	3.7E-3	8.5E-4
Krypton-87	3.4E-3	5.9E-4
Krypton-88	7.8E-3	1.6E-3
Manganese-54	2.3E-6	
Plutonium-239	1.7E-8	
Sulfur-35	1.8E-6	
Antimony-125	9.1E-6	
Strontium-90	4.0E-5	
Uranium-234	2.9E-5	
Uranium-235	8.7E-7	
Uranium-236	5.7E-8	
Uranium-238	9.0E-10	
Xenon-131m	2.5E-4	5.4E-5
Xenon-133m	1.4E-3	3.7E-4
Xenon-133	4.2E-2	1.0E-2
Xenon-135	4.0E-2	9.5E-3
Xenon-138	1.3E-3	

2.17.4 Health Impact Assessment of KAPL

All airborne particles released are assumed to be 1 micron in diameter and respirable. The assessment is based on all releases for the Knolls and Kesselrings sites being combined at a central point at the Knolls site. A release height of 10 meters was assumed for all effluents. Actual site boundary distances were used for the Knolls site and the Windsor site. Table 2.17-2 presents the dose rates from radionuclide emissions at these sites.

Knolls and Kesselring Sites

For the Knolls and Kesselring sites, the maximum individual was located 300 meters north of the release point. Ingestion was the major pathway of exposure.

Windsor Site

For the Windsor site, the maximum individual was located 110 m south of the release point. Inhalation was the major pathway of exposure.

Table 2.17-2. Radiation dose rates from radionuclide emissions from the Knolls and Kesselring Sites

Organ	Maximum individual (mrem/y)	
	Knolls and Kesselring sites	Windsor site
Endosteal	8.0E-2	3.4E-3
Red marrow	7.8E-2	3.6E-3
Muscle	5.0E-2	2.4E-3
Pulmonary	4.7E-2	
Lower large intestine	3.8E-2	1.8E-3
Stomach		1.7E-3
Weighted sum	4.9E-2	2.1

	Regional population (person-rem/y)	
	Knolls and Kesselring sites	Windsor site
Weighted sum	1.1E-1	2.1E-3

The lifetime risk to the maximum individual and the total number of fatal cancers per year of operation of these sites are listed in Table 2.17-3. Air immersion is the major pathway of exposure for these estimates.

Table 2.17-3. Fatal cancer risks due to radionuclide emissions from Knolls Atomic Power Laboratory

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Knolls and Kesselring sites	1E-6	3E-5
Windsor site	4E-8	3E-7

REFERENCES

DOE81 Department of Energy, Effluent Information System, 1981 Emissions Data, 1981.

DOE82 Department of Energy, Summary of Annual Environmental Reports for CY1980, DOE/EP-0038, 1982.

ERDA77 Energy Research and Development Administration, Environmental Monitoring at Major U.S. Energy Research and Development Administration Contractor Sites, Calendar Year 1976, Volumes 1 and 2, ERDA 77-104/1 & 2, Washington, D.C., 1977.

TRI Teknekron Research, Inc. Information Base for the Evaluation and Control of Radioactive Materials to Ambient Air, 1981.

2.18 Lawrence Berkeley Laboratory; Berkeley, California

2.18.1 General Description

Lawrence Berkeley Laboratory (LBL) is operated for the Department of Energy by the University of California-Berkeley. The Laboratory is located in the Berkeley Hills, above the University of California-Berkeley campus. The site is three kilometers from downtown Berkeley, about 20 kilometers from downtown Oakland, and 30 kilometers from downtown San Francisco. The population within a 50-mile radius of the Laboratory is 4.5 million. This includes most of the residents of the greater metropolitan San Francisco Bay area.

Lawrence Berkeley Laboratory is a large multifaceted research laboratory conducting programs of pure and applied research in physical, biological, and environmental sciences.

2.18.2 Process Description

LBL research facilities include four large accelerators, several small accelerators, a number of radiochemical laboratories, and a tritium labeling laboratory. The large accelerators include the Bevatron, the Super HILAC, the 224-centimeter Sector-Focused Cyclotron, and the 467 centimeter Cyclotron.

The Tritium Facility was designed to accommodate kilocurie quantities of tritium as a labeling agent for chemical and biomedical research. Radiochemical and radiobiological studies in many laboratories typically use millicurie quantities of various radionuclides.

2.18.3 Radionuclide Emissions

Radionuclide emissions during 1981 at Lawrence Berkeley Laboratory are shown in Table 2.18-1.

Table 2.18-1. Radionuclide emissions from Lawrence Berkeley Laboratory

Radionuclide	Emissions (Ci/y)
Carbon-14	3.6E-2
Cobalt-60	4.0E-5
Tritium	70.4
Iodine-125	5.7E-4
Plutonium-239	2.5E-9
Strontium-90	4.0E-5

2.18.4 Health Impact Assessment of Lawrence Berkeley Laboratory

Table 2.18-2 lists the estimates of the annual radiation doses resulting from radionuclide emissions. The maximum individual is located 100 meters east of the assumed release point. The predominant exposure pathway is ingestion (80 percent).

Table 2.18-3 gives the estimates of the maximum individual lifetime risk and the number of fatal cancers per year of operation. Ingestion is the major pathway for population exposure (74 percent).

Table 2.18-3. Radiation dose rates from radionuclide emissions from the Lawrence Berkeley Laboratory

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Thyroid	1.6	
Lower large intestine	6.8E-1	
Upper large intestine	5.5E-1	
Stomach	5.4E-1	
Small intestine	4.7E-1	
Weighted sum	5.0E-1	7.1E-1

Table 2.18-4. Fatal cancer risks due to radioactive emissions from the Lawrence Berkeley Laboratory

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
LBL	1E-5	2E-4

REFERENCES

DOE81 Department of Energy, Effluent Information System, 1981 Emissions Data, 1981.

LBL81 Lawrence Berkeley Laboratory, Annual Environmental Monitoring Report of the Lawrence Berkeley Laboratory, Report No. LBL-19553, University of California, Berkeley, California, 1981.

TRI79 Technekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Technekron Research, Inc., McLean, Virginia, 1979.

2.19 Mound Facility; Miamisburg, Ohio

2.19.1 General Description

Mound Facility is located in Miamisburg, Ohio, approximately 16 kilometers southwest of Dayton. Mound Facility has extensive programs in research and development (R&D), recovery and handling of tritium from solid waste, and development, fabrication, and testing of weapons components for the Department of Defense (DOD). Specific programs in these areas include the separation, purification, and sale of stable isotopes of noble gases and fabrication of chemical and radioisotopic heat sources for space and military applications.

2.19.2 Process Description

Nine buildings at the Mound Facility released radioactivity into the atmosphere in 1981. Operations at these facilities resulted in the release of tritium and plutonium-238.

Tritium was released in atmospheric effluents from the HH and SW Buildings. Operations at the HH Building involve the recovery of helium-3 which is contaminated with tritium. Gaseous wastes generated here are stored and transferred to the SW Building. At the SW Building operations involve disassembly, analysis and development of nuclear components containing tritium, and the recovery of tritium wastes. Tritium in gaseous effluents streams of the SW building are treated before release by the effluent removal system, which oxidizes elemental tritium and then removes the resulting tritiated water by molecular sieve drying beds.

Plutonium-238 was released in airborne effluents from H, PP, R, SM, WD, WDA, and 41 Buildings. Contaminated clothing is laundered at the H Building. Plutonium processing and other related activities are conducted at the PP Building. At the R Building plutonium heat source production is the principal activity. The SM Building is an idle contaminated facility. Operations at the WD, WDA, and 41 Buildings involve radioactive waste disposal processes. At all these facilities, particulate radioactivity is removed from process air streams by HEPA filters.

2.19.3 Radionuclide Emissions

Table 2.19-1 identifies radioactive emissions from nine buildings at the Mound Facility in 1981.

Table 2.19-1. 1981 Radionuclide emissions from the Mound Facility (Ci/y)

Source	Emissions (Ci/y)	
	Tritium	Plutonium-238
H Building stack		1.1E-10
HH Building stack	5.26E+1	
PP Building stack		1.21E-6
R Building stack		3.55E-7
SM Building stack		6.49E-6
SW Building		
SW stack	6.13E+2	
NCDPF stack	3.80E+2	
HEFS stack	3.24E+3	
WD Building		
WD sludge solidification stack		4.20E-8
WDA low risk stack		4.14E-8
WDA Building		
WDA low risk stack		1.07E-7
WDA high risk stack		2.50E-8
Building 41 stack	-------	2.31E-9
Total curie release	4.29E+3	8.28E-6

Total emissions are assumed to be released from the SW Building with an effective stack height of 61 meters. Table 2.19-2 compares the radioactive emissions from Mound for the years 1979 to 1981.

2.19.4 Health Impact Assessment of the Mound Facility

The estimated annual radiation doses resulting from radionuclide emissions from the Mound Facility are listed in Table 2.19-3. The manimum individual is located 1,500 meters north-northeast of the assumed release point (SW Building). Ingestion is the major pathway of exposure (78 percent).

Table 2.19-4 lists the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses. The regional population within an 80 kilometer radius of the site is 2.9 million. Ingestion is the major pathway for population exposure (68 percent).

Table 2.19-2. Radionuclide emissions from the Mound Facility 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Tritium	3.83E+3	3.80E+3	4.29E+3
Plutonium-238	1.17E-5	1.52E-5	8.28E-6

Table 2.19-3. Radiation dose rates from radionuclide emissions from the Mound Facility

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lower large intestine	2.9E-1	
Upper large intestine	2.3E-1	
Stomach	2.3E-1	
Endosteal	2.0E-1	
Kidneys	1.9E-1	
Weighted sum	1.9E-1	8.9

Table 2.19-4. Fatal cancer risks due to radioactive emissions from the Mound Facility

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Mound Facility	4E-6	3E-3

REFERENCES

DOE81 Department of Energy, Effluent Information System, 1981 Emissions Data, 1981.

EPA79 Environmental Protection Agency, Radiological Impact Caused by Emission of Radionuclides into Air in the United States, (Preliminary Report), EPA 520/7-79-006, Washington, D.C., August 1979.

FA82 Farmer B. M. and Carfagno D. G., Annual Environmental Monitoring Report:Calendar Year 1981, Report No. MLM-2930, Monsanto Research Corporation, Mound Facility, Miamisburg, Ohio, 1982.

2.20 Nevada Test Site; Nye County, Nevada

2.20.1 General Description

The Nevada Test Site (NTS) is located in Nye County, Nevada. The site is approximately 100 kilometers northwest of Las Vegas and covers an area of about 3,500 square kilometers.

NTS is part of DOE's nuclear weapons research and development complex. Programs at NTS include the development, redesign and maintenance of nuclear weapons, nuclear explosion effects studies, high-energy physics research, and seismic studies. Primary activities at NTS are centered around the testing of weapons. Tests are conducted at the site for DOE contractors (e.g., Lawrence Livermore Laboratories, Los Alamos Scientific Laboratory, Reynolds Electrical Engineering, and for the Department of Defense).

Additional research includes: testing non-nuclear high-explosives; and studies of nuclear energy systems (including gas core reactor testing), disposal of commercial radioactive waste, and storage of unreprocessed spent fuel.

2.20.2 Process Description

The Nevada Test Site is divided into six operational areas. Non-weapons programs are conducted in Area 27 and at the NTS experimental test farm (ERDA77a). Support facilities for most NTS activities are found in the Mercury vicinity. Underground test sites include Mesa vicinity (the NTS experimental farm is also located in this area) and Pahute Mesa vicinity (used for higher yield underground tests).

2.20.3 Radionuclide Emissions and Existing Control Technology

Radionuclides are released primarily from underground test sites. Activities responsible for these releases are conducted after underground nuclear detonations and include re-entry drilling operations and tunnel ventilations.

Reported releases for drill-back operations and tunnel ventilations are presented in Table 2.20-1. In addition to the monitored releases, the source terms from NTS should include the continuing release (due to leakage) of krypton and tritium. These releases have not been measured but are estimated to be several hundred curies per year. Plutonium also contributes to the source term because of resuspension of soil from contaminated areas, but there are no data quantifying such emissions. Energy research using the Super Kukla Reactor and experiments with waste disposal and fuel storage may possibly release radionuclides, but no releases have been reported for these operations.

During drill-back operations and tunnel ventilations, emissions are controlled by passing the air streams through HEPA filters to control particulates and through charcoal absorbers to control radioiodine (ERDA77a). There are no applicable controls for the continued leakage of noble gases and tritium. Although it is possible to reduce the quantities of plutonium in contaminated areas, these areas are being used for research into the behavior of plutonium in the environment (ERDA77a).

2.20.4 Health Impact Assessment of the Nevada Test Site

The estimated annual individual radiation dose equivalents from radionuclide emissions from the Nevada Test Site are shown in Table 2.20-2. The maximum individual is located 34,000 meters south of the assumed release point located near the center of the test site, and the weighted sum dose equivalent rate is 1.5E-3 mrem/y. Air immersion (57 percent) is the major pathway for the individual dose equivalent rate.

Table 2.20-3 lists the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population. The individual lifetime fatal cancer risk is 3E-8. The risk for the regional population per year of operation is 3E-7. Ingestion (77 percent) is the major pathway contributing to the fatal cancer risk.

Table 2.20-1. Radionuclide emissions from Nevada Test Site in 1981

Radionuclide	Emissions (Ci/y)
Tritium	534
Iodine-131	0.05
Xenon-133	2700
Xenon-133m	29
Xenon-135	142

Table 2.20-3. Radiation dose rates from radionuclide emissions from the Nevada Test Site

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Edosteal	2.1E-3	
Red marrow	2.1E-3	
Thyroid	1.8E-3	
Testes	1.6E-3	
Muscle	1.5E-3	
Weighted sum	1.5E-3	1.0E-3

Table 2.20-4. Fatal cancer risks due to radioactive emissions from the the Nevada Test Site

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
NTS	3E-8	3E-7

REFERENCES

DOE81 Department of Energy, Effluent Information System, 1981 Emissions Data, 1981.

ERDA77a U.S. Energy Research and Development Administration. Fianl Environmental Statement: Nevada Test Site, Nye County, Nevada, ERDA-1551, September 1977.

ERDA77b U.S. Energy Research and Development Administration. Environmental Monitoring at Major U.S. Energy Research and Development Administration Contractor Sites, Calendar Year, 1976, Volumes 1 and 2, ERDA 77-104/1 & 2, Washington, D.D., 1977.

2.21 Pantex Plant; Amarillo, Texas

2.21.1 General Description

The Pantex Plant is operated for the Department of Energy (DOE) by Mason & Hanger - Silas Mason Company, Inc. Pantex is a weapons testing and surveillance facility. Primary objectives of the plant include:

- fabrication and test firing of chemical high explosives,
- assembly of nuclear weapons,
- surveillance of atomic weapon stockpiles, and
- retirement of atomic weapons.

The Pantex Plant is situated on a 37 square kilometer site in the Texas panhandle, approximately 30 kilometers northeast of Amarillo, Texas.

The Pantex Plant is split into numerous areas and some areas are only 250 meters from the boundary. Land in the vicinity of Pantex is almost exclusively rural, with agricultural activities having the most significant impact on the area economy. Principal crops are wheat and grain sorghums. Cattle ranching and feeding are also of importance. There is almost no industry in the area.

The population within 80 kilometers of Pantex is approximately 218,000. This includes Amarillo, located 30 kilometers to the southwest with a population of 185,000, and Pampa, 65 kilometers to the northeast with a population of 21,000.

2.21.2 Process Description

The primary mission at Pantex involves assemblying, monitoring, and retiring atomic weapons. Significant quantities of plutonium, uranium, and tritium are handled during these activities. However, with few exceptions, these materials are handled only in sealed containers which are not opened at the site. Therefore, normal emissions at Pantex are limited, although the potential of an accident involving significant releases does exist.

Pantex conducts explosive test fires of chemical high explosives as a regular part of its operations. These test fires occur on an irregular basis, and vary in number from year to year. In recent years, all such tests were conducted at Firing Site 5, and the only radioactive material released was depleted uranium-238. The estimated annual releases have averaged 120 microcuries/year during the years surveyed.

2.21.3 Radionuclide Emissions and Existing Control Technology

Airborne emissions from Pantex for 1981 are given in Table 2.21-1. Tritium is emitted from the Assembly Area, and depleted uranium is the only radionuclide released from activities at Firing Site 5. The emissions for 1979 through 1981 are summarized in Table 2.21-2.

Reports issued by Pantex indicate that no control technology is being used in the assembly areas since all radioactive materials are handled in sealed containers. No control technologies are appropriate to the releases which result from the test firings, so atmospheric dilution is relied upon.

2.21.4 Health Impact Assessment for the Pantex Plant

For the purposes of dose/health effects assessment, it is assumed that all particles released are 1 micron or less in diameter and that all are respirable. The assessment is based on all emissions being combined into one central point on the site. Actual site boundary distances were used in the calculations.

The estimated annual radiation doses resulting from radionuclide emissions from the Pantex Plant are listed in Table 2.21-2. The offsite individual receiving the highest weighted sum dose equivalent rate is located 1,350 meters north of the release point. The major pathway contributing to the individual dose equivalent rate is inhalation (97 percent). The collective weighted sum dose equivalent rate is 7.9E-4 person-rem per year.

Table 2.21-3 lists the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population. The maximum individual fatal cancer risk is 1E-8. The estimated collective fatal cancer risk per year of operation is 1E-7. The pathway contributing primarily to the fatal cancer risk is inhalation.

Table 2.21-1. Radionuclide emissions from Pantex Plant 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
Tritium	2.0E-2	1.0E-1	9.5E-2
Uranium-238	3.0E-5	5.0E-5	1.0E-5

Table 2.21-3. Radiation dose rates from radionuclide emissions from the Pantex Plant

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Pulmonary	4.6E-3	
Lower large intestine	5.2E-5	
Upper large intestine	3.8E-5	
Kidneys	3.9E-5	
Weighted sum	1.4E-3	7.9E-4

Table 2.21-4. Fatal cancer risks due to radioactive emissions from the Pantex Plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Pantex Plant	1E-8	1E-7

REFERENCES

DOE81 Department of Energy, Effluent Information System, 1981 Emissions Data, 1981.

DOE82 Department of Energy, Summary of Annual Environmental Reports for CY1980, DOE/EP-0038, 1982.

ERDA77 Energy Research and Development Administration. Environmental Moniroring at Major U.S. Energy Research and Development Administration Contractor Sites, Calendar Year 1976, Volumes 1 & 2, ERDA 77-104/1 & /2, Washington, D.C., 1977.

MHSMP82 Environmental Monitoring Report for Pantex Plant Covering 1981, MHSMP-82-14, 1982.

TRI81 Teknekron Research, Inc., Information Base for the Evaluation and Control of Radioactive Materials to Ambient Air, 1981.

2.22 Pinellas Plant; Pinellas County, Florida

2.22.1 General Description

The Pinellas Plant is operated by the Neutron Devices Department of the General Electric Company. The plant is located on a 39-hectare site in the center of Pinellas County, Florida, approximately 10 kilometers northwest of St. Petersburg. Pinellas is an integral part of the nation's weapons program. Major operations include the design, development, and manufacture of special electronic and mechanical nuclear weapons components.

2.22.2 Process Description

The principal operations causing atmospheric releases of radioactive materials are not described in the literature. However, they involve neutron generator development and production, testing, and laboratory operations.

Small sealed plutonium capsules are used as heat sources in the manufacture of radioisotopic thermoelectric generators at Pinellas Plant. These sources are triply encapsulated so as to prevent release of plutonium to the atmosphere.

2.22.3 Radionuclide Emissions and Control Technology

The principal releases of radioactivity reported are tritium gas, tritium oxide, krypton-85, and carbon-14. Locations and quantities of releases reported are in Table 2.22-1.

Areas utilizing radioactive materials are connected to a special exhaust system which is designed to trap tritium and reduce the amount released to the atmosphere. In this system tritium gas is converted to the oxide form by passage through heated copper oxide beds. Then the tritiated water vapor is absorbed by silical gel.

2.22.4 Health Impact Assessment of Pinellas Plant

The estimated annual individual radiation dose equivalents from radionuclide emissions from the Pinellas Plant are shown in Table 2.22-2. The maximum exposed individual is located 470 meters west of the release point. Ingestion (78 percent) is the major contributor to the individual dose equivalent rate.

The risks of fatal cancer are shown in Table 2.22-3. The risk for the regional population per year of operation is 3E-4. The individual lifetime fatal cancer risk is 5E-6. Inhalation was the pathway contributing 51 percent of the fatal cancer risk; ingestion was the pathway contributing 49 percent of the risk.

Table 2.22-1. Radionuclide emissions from Pinellas Plant

Radionuclide	Emissions (Ci/y) Main Stack	Laboratory Stack	Building 800
Tritium gas	129.2	89.7	2.81
Tritium oxide	115.3	75.4	4.63
Krypton-85	3.7	--	--
Carbon-14	--	8.5E-5	--

Table 2.6-3. Radiation dose rates from radionuclide emissions from the Pinellas Plant

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lower large intestine	3.8E-1	
Upper large intestine	3.1E-1	
Stomach	3.0E-1	
Small intestine	2.6E-1	
Kidneys	2.5E-1	
Weighted sum	2.5E-1	8.8E-1

Table 2.6-4. Fatal cancer risks due to radioactive emissions from the Pinellas Plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Pinellas Plant	5E-6	3E-4

REFERENCES

DOE81 Department of Energy, Effluent Information System, 1981 Emissions Data, 1981.

EPA79 Environmental Protection Agency Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, Preliminary Report, EPA 520/7-79-006.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, Inc., McLean, Virginia, 1979.

2.23 Rockwell International; Santa Susana, California

2.23.1 General Description

Rockwell International, a division of Rockwell International Corporation, has two nuclear energy research and development sites in the Los Angeles area. Current programs at these two facilities include the fabrication of test reactor fuel, decontamination, and the design, production, and testing of components and systems for central power plants.

Canoga Park, the headquarters site, is approximately 37 kilometers northwest of downtown Los Angeles. Facilities at Canoga Park are used for administrative activities and for NRC- and State-licensed programs. The Santa Susana site (SSFL) is situated in the Simi Hills of Ventura County, approximately 48 kilometers northwest of Los Angeles. Facilities owned by the Department of Energy (DOE), as well as Rockwell-owned NRC- and State-licensed facilities, are located at SSFL.

2.23.2 Process Description

NRC- and State-licensed activities at Canoga Park include uranium fuel production (Building 001), research in analytical chemistry (Building 004), and cobalt-60 gamma irradiation studies. Non-DOE facilities at the Santa Susana site include the Rockwell International Hot Laboratory (RIHL) (Building 020), the Nuclear Materials Development Facility (NMDF) (Building 055), a neutron radiography facility containing the L-85 nuclear examination and research reactor (Building 093), and several X-radiography inspection facilities.

DOE operations at the Santa Susana site that release radioactive materials into the atmosphere are conducted at the Radioactive Material Disposal Facility (RMDF). The two buildings (021-022) that constitute this facility are used for processing wastes generated by a program for the decontamination and disposition of DOE facilities. HEPA filters are in use at RMDF.

2.23.3 Radionuclide Emissions

Table 2.23-1 compares radioactive releases for the years 1979-1981. The 1981 release information is used in the health impact assessment section.

Table 2.23-2. Radionuclide emissions from the SSFL (DOE facilities only), 1979 to 1981 (Ci/y)

Radionuclide	1979	1980	1981
MFP(a)	2.8E-6	1.8E-6	4.1E-6

(a)Mixed fission products; assumed to be strontium-90 for health impact assessment.

The total emissions are assumed to originate from Buildings 21 and 22 with an effective stack height of 30 meters.

2.23.4 Health Impact Assessment of Rockwell International

The estimated annual radiation doses resulting from radionuclide emissions Rockwell International Plant are listed in Table 2.23-2. The maximum individual is located 180 meters north of the assumed release point (Buildings 21 and 22). Ingestion is the predominant exposure pathway and is responsible for 71 percent of the dose.

Table 2.23-3 lists the estimates of the maximum individual lifetime risk and the number of fatal cancers per year of operation. Ingestion is the primary pathway for population exposure. The regional population within 80 kilometers of the site is 8 million.

Table 2.6-3. Radiation dose rates from radionuclide emissions from the Rockwell International Plant

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Endosteal cells	4.1E-5	
Red marrow	2.1E-5	
Lower large intestine	1.5E-6	
Upper large intestine	3.5E-7	
Thyroid	2.8E-7	
Weighted sum	4.0E-6	1.1E-4

Table 2.6-4. Fatal cancer risks due to radioactive emissions from the Rockwell International Plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Rockwell	7E-11	3E-8

REFERENCES

DOE81 Department of Energy. Effluent Information System, Department of Energy, Washington, D.C., 1981.

EPA79 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, (Preliminary Report), EPA 520/7-79-006, Washington, D.C., August 1979.

ESG82 Energy Systems Group, Environmental Monitoring and Facility Effluent Annual Report 1981, ESG-82-21, Rockwell International, Canoga Park, California, 1982.

2.24 Sandia National Laboratories; Albuquerque, New Mexico

2.24.1 General Description

Sandia National Laboratoraies (SNL) is a nuclear ordinance laboratory with locations in Albuquerque, New Mexico, and Livermore, California. The Livermore site is discussed in Section 2.6 under the discussion of the Lawrence Livermore Laboratory. Sandia Laboratories serves as an interface between the nuclear weapons developed at the Los Alamos and Livermore Laboratories and military delivery systems. The Sandia site is located within the limits of Kirkland Air Force Base, 10 kilometers south of Albuquerque. Facilities at Albuquerque are grouped in five Technical Areas (TAs).

2.24.2 Process Description

The operations at SNL involve testing weapons for quality assurance and safeguards, arming, and fusing nuclear weapons, and developing modifications to delivery systems. The major facilities include the Sandia Pulsed Reactor and the Annular Core Pulsed Reactor, which are used to irradiate test materials, and the Relativistic Electron Beam Accelerator. Support facilities include the Neutron Generator Facility, the Tube Loading Facility, the Fusion Target Loading Facility, the Tritium Laboratory, and the Nondestructive Test Facility. These facilities are located at Technical Areas I and V. TA-I, located in the northwest corner of the site, also houses research and design laboratories. TA-III is the location for the Sandia low-level radioactive waste dump.

2.24.3 Radioactive Emissions and Control Technology

Airborne releases from operation at SNL, Albuquerque, are summarized in Table 2.24-1.

Table 2.24-1. Radionuclide emissions from Sandia National Laboratories, 1981

Radionuclide	Emissions (Ci/y)
Argon-41	6.84

2.24.4 Health Impact Assessment of Sandia National Laboratories

The entire site is treated as a single ground level point source release located centrally within the facility. For the purpose of dose/health assessment, it is assumed that all particulates released are 1 micron or less in diameter and all releases are respirable. Actual site boundary distances were used in the calculations.

Table 2.24-2 lists the estimated annual radiation doses from radionuclide emissions from Sandia National Laboratories at Albuquerque. The offsite individual receiving the high dose equivalent rate was 3200 meters west-northwest of the source; the weighted sum dose equivalent rate was 7.8E-4 mrem per year. Air immersion contributed essentially 100 percent to the observed dose equivalent rate and fatal cancer risk.

Table 2.24-3 lists the estimates of the maximum individual lifetime risks and the number of fatal cancers to the regional population. The individual lifetime fatal cancer risk was 2E-8 and the estimated collective fatal cancer risk per year of operation was 10E-7. Air immersion contributed essentially 100 percent of the fatal cancer risk.

Table 2.24-3. Radiation dose rates from radionuclide emissions Sandia National Laboratories

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Spleen	8.7E-4	
Endosteal	8.5E-4	
Muscle	8.1E-4	
Red marrow	8.0E-4	
Upper large intestine	7.9E-4	
Weighted sum	7.8E-4	3.2E-3

Table 2.24-4. Fatal cancer risks due to radioactive emissions from Sandia National Laboratories

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
SNL	2E-8	1E-6

REFERENCES

DOE81 Department of Energy, Effluent Information System, 1981 Emissions Data, 1981.

DOE82 Department of Energy, Summary of Annual Environmental Reports for CY1980, DOE/EP-0038, 1982.

ERDA77 Energy Research and Development Administration. Environmental Moniroring at Major U.S. Energy Research and Development Administration Contractor Sites, Calendar Year 1976, Volumes 1 & 2, ERDA 77-104/1 & /2, Washington, D.C., 1977.

SNL82 1981 Environmental Monitoring Report, Sandia National Laboratories, SAND-82-0833, 1982.

TRI Teknekron Research, Inc., Information Base for the Evaluation and Control of Radioactive Materials to Ambient Air, 1981.

2.25 Shippingport Atomic Power Station; Beaver County, Pennsylvania

2.25.1 General Description

The Shippingport Atomic Power Station, operated by the Duquesne Light Company for the Department of Energy, was the first large scale central station nuclear reactor in the United States. Initial power generation was achieved in December 1957. In 1977 the station was shut down for the installation of the light water breeder reactor (LWBR) core; initial criticality was achieved in August 1977 and full power in September 1977.

The Shippingport Atomic Power Station is located on the same site as the Beaver Valley Power Station, also operated by the Duquesne Light Company. The site is a 2.8 square kilometer tract of land located along the Ohio River in the Borough of Shippingport, Beaver County, Pennsylvania. The site is approximately 40 kilometers northwest of Pittsburgh. Beaver County, Pennsylvania, is considered an integral part of the greater Pittsburgh industrial complex. There are approximately 3.8 million people living within 80 kilometers of the site.

2.25.2 Process Description

The nuclear reactor at Shippingport Atomic Power Station is a pressurized water reactor (PWR); however, it has the LWBR core which operates on the basis of the thorium fuel cycle. The reactor fuel is in the form of ceramic fuel pellets with uranium-233 as the fissile material and thorium-232 the fertile material. The major difference in operation of the LWBR core from previous PWR cores, other than the type of fuel, is that the reactivity behavior of the LWBR core is controlled by movable seed or fissile fuel elements rather than by traditional control rods.

2.25.3 Radionuclide Emissions and Control Technology

The potential source of radioactive airborne emissions is the reactor coolant system which contains activated corrosion and wear products, activated impurities, and small quantities of fission products. The radioactivity can be released and become airborne from coolant leaks, sampling operations, and maintenance and overhaul operations.

Table 2.25-1 summarizes the emissions from Shippingport Atomic Power station in 1977 and 1981. Since the plant was not in operation the entire year in 1977, the 1977 releases are estimated emissions to the atmosphere for that year.

Gaseous wastes stripped from the reactor coolant are circulated through a hydrogen analyzer and catalytic hydrogen burner system where the hydrogen is removed. The gases are initially stored in a vent gas surge drum, sampled, and subsequently compressed and transferred to one of four gas storage drums. After a long decay period, the decayed gases are sampled again before release. In addition, the exhaust from the containment is equipped with high efficiency filters to prevent release of radioactive particulates. Protective devices will automatically seal off the primary containment to prevent an inadvertent release of radioactivity. Reactor plant exhausts from the Decontamination Room, Sample Preparation Room, Laundry Room, Radiochemistry Laboratory, Gaseous Waste System, and Compacting Station are also equipped with high efficiency filters and are continuously monitored for radioactive particulates by fixed filter monitors.

Table 2.25-1. Radionuclide emissions from Shippingport Atomic Power Station for 1977 and 1981

Radionuclide	Emissions (Ci/y) 1977[(a)]	1981
Argon-41	2.4	-
Carbon-14	-	7.2E-2
Cobalt-60	3.7E-8	3.7E-8
Krypton-83m	1.1E-2	-
Krypton-85m	1.8E-2	-
Krypton-85	2.5E-6	6.0E-7
Krypton-87	3.3E-2	-
Krypton-88	5.7E-2	-
Manganese-54	3.8E-9	-
Iodine-130	7.0E-7	-
Iodine-131	6.4E-5	-
Iodine-132	4.6E-3	-
Iodine-133	1.0E-3	-
Iodine-134	1.1E-2	-
Iodine-135	2.4E-3	-
Tritium	-	8.9E-1
Xenon-131m	3.0E-8	-
Xenon-133m	6.1E-4	-
Xenon-133	6.0E-2	2.4E-4
Xenon-135	1.9E-1	-
Xenon-135m	4.9E-2	-
Xenon-137	1.8E-1	-
Xenon-138	1.5E-2	-

(a)Estimated for entire year.

2.25.4 Health Impact Assessment of Shippingport Atomic Power Station

No health impact assessment was made with the 1981 emission data. The health impacts reported in TRI79 (using 1977 data) are summarized in Tables 2.25-2 and 2.25-3.

Table 2.25-2. Radiation dose rates from radionuclide emissions from the Shippingport Atomic Power Station, 1977 (TRI79)

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Bone	2.8E-4	5.4E-3
Red marrow	2.7E-4	5.1E-3
Muscle	2.7E-4	5.0E-3
Lung	2.5E-4	4.8E-3
Liver	2.2E-4	4.3E-3
Weighted sum	2.6E-4	5.3E-3

Table 2.26-3. Fatal cancer risk due to radionuclide emissions Shippingport Atomic Power Station, 1977 (TRI79)

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Shippingport	5E-9	1E-6

REFERENCES

DLC78 Duquesne Light Company, 1978, 1977 Environmental Report, Radiological - Volume #2, Duquesne Light Company, Beaver Valley Power Station and Shippingport Atomic Power Station.

DOE77a Department of Energy, 1977, Effluent Information System Report No. 02, Narrative Summary Data Base Master List, EIS 02, (Computer Listing).

DOE77b Department of Energy, 1977, Effluent Information System Report No. 51, Release Point Analysis report for Calendar Year 1977, EIS 51, (Computer Listing)

DOE81 Department of Energy, Effluent Information System, 1981 Emissions Data, 1981.

EPA79 Environmental Protection Agency, Radiological Impact Caused by Emission of Radionuclides into Air in the United States, (Preliminary Report), EPA 520/7-79-006, Washington, D.C., August 1979.

ERDA76 Energy Research and Development Agency, 1976, Final Environmental Statement, Light Water Breeder Reactor Program, ERDA-1541, Washington, D.C.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (unpublished), Teknekron Research, Inc., McLean, Virginia, 1979.

2.26 Stanford Linear Accelerator Center; Stanford, California

2.26.1 General Description

The Stanford Linear Accelerator (SLAC) is located in the San Francisco Bay Area roughly halfway between San Francisco and San Jose. The total length of the accelerator and the experimental area is approximately 4.8 kilometers, oriented almost east-west, on about 1.7 square kilometers of Stanford University land. There are 4.2 million people living in the six counties of the San Francisco Bay Area.

SLAC is a large research laboratory devoted to theoretical and experimental research in high energy physics and to the development of new techniques in high energy accelerator particle detectors. The main tool of the laboratory is a linear accelerator which is used to accelerate electrons and positrons.

2.26.2 Process Description

The linear accelerator is approximately 3.2 kilometers long and produces beams of electrons with energies up to 31 billion electron volts (31 GeV). It can also accelerate positrons, up to 20 GeV. These beams can be used directly for experiments or they can be transported into either of two storage-ring facilities-SPEAR or PEP. These storage-rings are major laboratory facilities, roughly circular in shape, in which electrons and positrons brought from the accelerator are stored and circulated continuously in opposite directions. The energies are 4.5 and 18 GeV per beam for SPEAR and PEP, giving total collision energies of 9 and 36 GeV, respectively. SPEAR has been in operation since 1972 and PEP was first filled with beam on April 13, 1980.

With colliding beam storage rings, such as SPEAR and PEP, the beam particles are truly 'recycled'; the same particles are brought into collision over and over again, rather than striking a target only once. For this reason colliding beam devices produce much less radiation and residual radioactivity than do conventional accelerators.

2.26.3 Radionuclide Emissions and Control Technology

Airborne radioactivity produced as a result of SLAC operations and respective half-lives of the radionuclides are listed in Table 2.26-1. During 1981 only 1.1 curies of gaseous radioactivity were released. For calculational purposes the total release is assumed to be argon-41. No measurable particulate radioactivity was released.

SLAC does not routinely vent the facility while the beam is on. There is a waiting period to allow all isotopes, with the exception of argon-41, to decay before exhausting the facility. The release of radioactivity is, therefore, infrequent and limited to argon-41 for brief periods of 30 to 60 minutes.

If personnel entry must be made during an operating cycle, the facility is vented for 10 minutes prior to entry and after the primary beam has been shut off. This practice may result in the release of small quantities of radionuclides other than argon-41.

Control Technology

The primary control of airborne radioactive emissions is hold-up confinement.

The accelerator, SPEAR and PEP do not represent measurable sources of gaseous or particulate radioactivity due to low activating potential.

2.26.4 Health Impact Assessment of Stanford Linear Accelerator

The estimated annual radiation doses resulting from radionuclide emissions from Stanford Linear Accelerator are listed in Table 2.26-2. The maximum individual is located 250 meters south of the release location and the predominant exposure pathway is air immersion.

Table 2.26-3 lists the estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses. The lifetime risk to the maximum individual is estimated to be 1E-7 and the total number of fatal cancers per year of operations of the accelerator is estimated to be 9E-6.

Table 2.26-1. Radionuclide emissions from
Stanford Linear Accelerator, 1981

Radionuclide	Half-life
Oxygen-15	2.1 minutes
Nitrogen-13	9.9 minutes
Carbon-11	20.5 minutes
Argon-41	1.8 hours
Total activity	1.1 curies

Table 2.26-2. Radiation dose rates from radionuclide emissions from Stanford Linear Accelerator

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Spleen	5.7E-3	3.7E-2
Endosteal	5.6E-3	3.6E-2
Muscle	5.3E-3	3.4E-2
Red Marrow	5.3E-3	3.4E-2
ULI Wall	5.2E-3	3.3E-2
Weighted Sum	5.0E-3	3.2E-2

Table 2.26-3. Fatal cancer risk due to radionuclide emissions from Stanford Linear Accelerator

Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
1E-7	9E-6

REFERENCES

DOE81a Department of Energy, Environmental Monitoring Report for Stanford Linear Accelerator Center, Annual Report for CY 1981, Stanford University, Stanford, California, 1981.

DOE81b Department of Energy, Effluent Information System, Department of Energy, Washington, D.C., 1981.

TRI79 Teknekron Research, Inc., Technical Support for the Evaluation and Control of Emissions of Radioactive Materials to Ambient Air (Unpublished), Teknekron Research Inc., McLean, Virginia, 1979.

2.27 Worldwide Impact of Selected Radionuclides

Some radionuclides released from a site may have worldwide health consequences from their dispersion in the biosphere and their relatively long half-life. The emissions of carbon-14, iodine-129 and krypton-85 from all Department of Energy sites were considered in this regard (Table 2.27-1).

Carbon-14

By combining the emission of 67 Ci per year and the dose equivalent conversion of 700 person-rem per Ci released, a worldwide dose equivalent of 47,000 person-rem were committed from 1981 emissions of carbon-14. Similarly, the estimate of fatal cancers committed due to these emissions (using 0.08 fatal cancers per Ci--Table 2.27-2) is 5. Those effects will be observed during the time it takes carbon-14 to decay away, or over approximately 40,000 years.

Iodine-129 and Krypton-85

The worldwide health impact of emissions of iodine-129 and krypton-85 are of similar concern. In 1981, 0.19 Ci of iodine-129 and 910,000 Ci of krypton-85 were released from operations at all DOE sites.

The committed collective dose equivalent due to iodine-129 was 50,000 person-rem; for krypton-85, 4000 person-rem.

Health effects conversion factors taken from Table 2.27-2 were used to calculate estimated fatal cancers committed over the entire environmental residence time of iodine-129 and krypton-85. For iodine-129 this was 10 fatal cancers and for the krypton-85 this yielded an estimated 0.7 fatal cancers. Both of these calculated values are based on an assumption of 200 fatal cancers per million person-rem received by the world population.

Table 2.27-1. Emissions of selected radionuclides from DOE facilities which may lead to worldwide impact

Source[a]	Emissions (Ci/y) Carbon-14	Emissions (Ci/y) Iodine-129	Emissions (Ci/y) Krypton-85
Argonne National Laboratory	0	0	6.7
Brookhaven National Laboratory	8.1E-4	0	0
Hanford Reservation	3.2	0	0
Idaho National Engineering Laboratory	1.7E-1	3.7E-2	5.9E+4
Oak Ridge Reservation	1.2E-3	0	6.6E+3
Savannah River Plant	6.4E+1	1.5E-1	8.4E+5
Combined releases for all DOE facilities	6.7E+1	1.9E-1	9.1E+5

[a] DOE facility having significant releases of selected radionuclides.

Table 2.27-2. Estimated radiation doses and fatal cancers from emissions of selected radionuclides from DOE facilities to the world population

Radionuclide	World population (person-rem/Ci)	World population (Fatal cancers/ Ci release)
Carbon-14	[a] 7E+2	[c] 8E-2
Krypton-85	[b] 4E-3	[d,f] 8E-7
Iodine-129	[e] 2.8E+5	[f] 6E+1

[a] Dose equivalent recorded by red marrow and endosteal cells, (Un77, p. 120).

[b] Dose equivalent is received by the skin (Un77, p. 121).

[c] Health effects integrated over all time (Fo79).

[d] (NCRP75).

[e] Ko81.

[f] Assumed 200 fatal cancer per million person-rem received.

REFERENCES

Fo79 Fowler T. W. and Nelson C. B., Health Impact Assessment of Carbon-14 Emissions from Normal Operations of Uranium Fuel Cycle Facilities, EPA 520/5-80-004, Office of Radiation Programs, Environmental Protection Agency, Washington, D.C., 1979.

Ko81 Kocher, D. C., A Dynamic Model of the Global Iodine Cycle and Estimation of Dose to the World Population from Releases to the Environment, Environment International, Vol. 5, 15-31, 1981.

NCRP75 National Council on Radiological Protection, Krypton-85 in the Atmosphere, Report No. 44, 1975.

UN77 United Nations Scientific Committee on the Effects of Atomic Radiation, Sources and Effects of Ionizing Radiation, Annex C, 1977.

2.28 Future operations at DOE Facilities

2.28(A) Resumption of operations at the PUREX Plant

The U.S. Department of Energy has proposed the resumption of fuel reprocessing in the PUREX plant in the 200 area of the Hanford site. If the resumption occurs as scheduled, atmospheric releases will be significantly increased from their present value. For this reason, the risk from the expected atmospheric emissions have been calculated for operation of the PUREX plant in the 200 Area of the Hanford site.

Process Description

The PUREX process is based on dissolution, solvent-extraction, and ion-exchange and is used to recover uranium, plutonium, and neptunium from the N-Reactor's irradiated fuel elements. Wastes generated during the process are treated and returned to the process flow or shipped to the AR Vault for disposal. The PUREX Plant has been operated on an intermittent schedule, determined by national security needs and the production of the N-Reactor. The plant has been on standby since 1972, but a draft Environmental Impact Statement (DOE/EIS-0089D) indicates that PUREX will be reactivated in 1984 for additional reprocessing of N-reactor fuel. The PUREX Plant was in operation for 17 years between 1950 and 1972 for separating plutonium from reactor fuel elements produced by the operating reactors in the 100 Area of Hanford.

The plant is expected to reprocess up to 3000 MT of N-reactor fuel per year. Estimated releases from PUREX during the forthcoming operation have been estimated by DOE using experience gained during the previous operation as well as the effects of improved control technology which have been added since 1975. A summary of these estimated atmospheric releases are given in Table 2.28(A)-1.

Radionuclide Emissions and Existing Control Technology at Purex

Table 2.28(A)-1 gives the estimated airborne releases from PUREX plant assuming a fuel reprocessing rate of 3000 MT per year. Airborne effluents from all PUREX release points are passed through acid scrubbers, deentrainers, fiberglass filters, and HEPA filters prior to release. In addition, emissions from the PUREX plant are passed through a silver nitrate reactor to remove elemental iodine.

Health Impact Assessment from Operations at the PUREX Plant

The estimated radiation dose rates from resumed operation of the PUREX Plant are given in Table 2.28(A)-2. The offsite individual receiving the highest dose equivalent is located 16,000 m south of the source. The major pathway contributing to the individual dose equivalent rate is air immersion (43 percent). The five organs receiving the five highest dose equivalent rate are endosteal cells, 4.8 mrem/yr; red marrow, 2.1 mrem/yr; pulmonary tissue, 2.1 mrem/yr; thyroid, 1.5 mrem/yr and liver, 1.0 mrem/yr.

The maximum individual lifetime fatal cancer risk is 3E-5. The estimated collective fatal cancer risk per year of operation is 7E-3 (See Table 2.28(A)-3). Note that this is comparable to the fatal cancer risk from operation of the other major areas at the Hanford site (compare with Table 2.4-3).

Table 2.28(A)-1. Estimated radionuclide emssionsions from resumed operation of the PUREX plant

Radionuclides	Emissions (Ci/y)
Carbon-14	9.0
Tritium	3.0E+3
Iodine-129	5.1E-1
Iodine-131	3.0E-1
Krypton-85	3.3E+6
Plutonium-239	5.7E-3
Strontium-90	1.2

Table 2.28(A)-2 Estimated radiation dose rates from resumed operation of the PUREX plant

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Red marrow	2.1	
Endosteal	4.8	
Pulmonary	2.1	
Liver	1.0	
Thyroid	1.5	
Weighted sum	1.4	3.2E+1

Table 2.28(A)-3. Estimated fatal cancer risks from resumed operation of the PUREX plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
PUREX Plant	3E-5	7E-3

2.28(B) Resumption of L-Reactor Operations at Savannah River Plant

The U.S. Department of Energy has proposed resumption of operation of the L-Reactor at Savannah River Plant.

Process Description

The L-Reactor has been used to provide raw materials for nuclear weapons; it has been shut down since 1968. The plant is scheduled to be capable of operation no later than October 1983.

Radionuclide Emissions From L-Reactor Operations

Table 2.28(B)-1 gives the estimated annual emissions from resumed operations of L-Reactor. Emissions of tritium, argon-41 and xenon are the most significant radionuclides based on the quantity released.

Health Impact Assessment from Operations of the L-Reactor

The estimated dose rates from resumption of the L-Reactor are given in Table 2.28(B)-2 for the individual at the location of highest risk. This location is onsite; the risk to offsite individuals is an order of magnitude less. The highest organ doses are received by the lower large intestine, 5.7 mrem/y; upper large intestine, 5.3 mrem/y; stomach, 5.0 mrem/y; spleen, 4.6 mrem/y and red marrow, 4.6 mrem/y. Ingestion is the major pathway for weighted sum dose equivalent rate (49 percent).

An assessment of the health impact from emissions from resumed operation of the L-Reactor indicates an estimated onsite individual lifetime fatal cancer risk of 1E-4 (Table 2.28(B)-3). The estimated collective cancer risk per year of operation is 5E-3 with 85 percent of the risk due to tritium (Table 2.28(B)-3). Ingestion is also the major contributing pathway to health risk (72 percent).

Table 2.28(B)-1 Estimated radionuclide emissions from resumption of L-Reactor operations at the Savannah River Plant

Radionuclides	Emissions (Ci/yr)
Tritium	5.5E+4
Carbon-14	1.2E+1
Argon-41	2.0E+4
Krypton-85m	6.0E+2
Krypton-87	5.4E+2
Krypton-88	8.0E+2
Xenon-133	1.7E+3
Xenon-135	1.4E+3
Iodine-129	1.0E-4
Iodine-131	4.1E-3
Plutonium-239	5.0E-7
Americium-241	5.0E-7
Strontium-90	1.0E-4

Table 2.28(B)-2. Estimated radiation dose rates from resumption of the L-Reactor, Savannah River Laboratory

Organ	Maximum individual(a) (mrem/y)	Regional population (person-rem/y)
Red marrow	4.6	15.9
Stomach	5.0	18.2
Lower large intestine	5.7	22.2
Upper large intestine	5.3	18.8
Spleen	4.6	15.6
Weighted sum dose equivalet rate	4.5	15.8

(a)At onsite location of highest risk.

Table 2.28(B)-3. Fatal cancer risks due to radionuclide emissions from resumption of the L-Reactor, Savannah River Laboratory

Source	Lifetime risk[a] to maximum individual	Regional population (Fatal cancers/y of operation)
L-Reactor	1E-4	5E-3

[a] At onsite location of highest risk.

REFERENCES

DOE82a Department of Energy, Draft Environmental Impact Statement, Operation of PUREX and Uranium Oxide Plant Facilities, DOE/EIS-0089D, 1982.

DOE82b Department of Energy, Environmental Assessment, L-Reactor Operation, Savannah River Plant, DOE/EA-0195, 1982.

Chapter 3: NRC-LICENSED FACILITIES AND NON-DOE FEDERAL FACILITIES

3.1 Research and Test Reactors

3.1.1 General Description

This category consists of those land-based reactors licensed by the Nuclear Regulatory Commission that are operated for purposes other than commercial power production. These uses include basic and applied research and teaching. There are currently 70 such reactors licensed to operate in the United States.

3.1.2 Process Description

Research and test reactors are of a wide variety of designs, are used for different purposes, and operate over a wide range of power levels. The design types include heavy water, graphite, tank, pool, homogeneous solid, and uranium-zirconium hydride. Purposes include testing of reactor designs, reactor components, and safety features; basic and applied research in the fields of physics, biology, and chemistry; and education. Power levels range from near zero to 10 MW.

3.1.3 Control Technology

There is no demonstrated treatment technology for control of emissions of argon-41 from these reactors.

Emissions of tritium are not currently controlled but could be controlled by use of a catalytic recombiner.

Emissions of both argon-41 and tritium could be reduced by reducing the amount of time the reactor operates. Argon-41 emissions could also be controlled by reducing the amount of air that is irradiated by neutrons, by such techniques as filling voids with an inert gas and sealing leaks of air into the reactor compartment.

3.1.4 Radionuclide Emissions

Airborne emissions of radioactive materials from research and test reactors usually contain argon-41 and tritium as the principal radioactive constituents, and may also contain very small quantities of other noble gases and some fission products. Some reactors use filters to remove the small amount of fission products which may be present; others use no controls.

Research and test reactors are not required to submit data on air emissions of radionuclides to the Nuclear Regulatory Commission (NRC). However, some reactor owners do submit these data as part of their annual operating report. A list of research and test reactors by design type, which includes their reported radionuclide emissions to air, is given in Table 3.1-1.

3.1.5 Reference Facility

Table 3.1-2 describes the parameters of a reference reactor used to estimate the maximum impact on human health. The atmospheric emissions for the reference facility were chosen as equal to those for the facility with the highest values shown in Table 3.1-1, and the actual stack height (50 m) of that facility was used. Other parameters used in the analysis were assumed to be equal to those for a major metropolitan area in the northeastern United States.

3.1.6 Health Impact Assessment of Reference Facility

The estimated annual radiation doses from the reference facility for individuals and population groups are shown in Table 3.1-3. Individual fatal cancer risks and committed population fatal cancers are presented in Table 3.1-4. The lifetime fatal cancer risk to the individual at highest risk is estimated to be 2E-5. The individual at highest risk is located 1000 meters north of the stack.

The estimated number of potential fatal cancers to the population living in the region around the reference facility is estimated to be 0.1 per year of reactor operation.

3.1.7 Total Health Impact from Research and Test Reactors

The reference facility emits far more radioactivity than the average research or test reactor for which data are available. The 47 reactors for which argon-41 data are available report an average annual release of 291 curies of argon-41. If we assume that each of the 23 reactors for which emission data are not available emits 291 curies of argon-41 per year, then the total annual emissions from all 70 reactors is 20,400 curies of argon-41. The reference facility emits 48 percent of this total. Assuming that the reference facility also causes 48 percent of the total health impact, that impact is 0.2 fatal cancers per year.

3.1.8 Existing Emission Standards and Air Pollution Controls

Research and test reactors licensed by NRC are subject to the requirements of 10 CFR 20.106, which places limits on air emissions to unrestricted areas. Argon-41 is limited to an air concentration of 4×10^{-8} microcuries per milliliter above background, and tritium is limited to an air concentration of 2×10^{-7} microcuries per milliliter.

Table 3.1-1. Radionuclide emissions from research and test reactors

Design type	Power (kW)	Radionuclide	Emissions (Ci/y)
1. Heavy water	10,000	Argon-41 Tritium	465.0 155.0
2. Tank	10,000	Argon-41 Tritium	2504 16.3
3. Heavy water	5,000		N/A
4. Heavy water	5,000	Argon-41 Tritium	9700 8
5. Pool	5,000	Argon-41	350
6. Pool	2,000	Argon-41	247.0
7. Pool	2,000	Noble gas Radioiodine Particulate	47.3 0.021 0.01
8. Pool	2,000		N/A
9. Pool	2,000	Argon-41	6.64
10. TRIGA	1,500	Argon-41	0.09
11. TRIGA	1,500	Argon-41	2.1
12. Pool	1,000		N/A
13. TRIGA	1,000	Argon-41	9.2
14. TRIGA	1,000	Argon-41	7.15
15. TRIGA	1,000	Argon-41	2.9
16. Pool	1,000	Argon-41	14.03
17. Pool	1,000	Argon-41	9.96
18. TRIGA	1,000	Argon-41	41.7
19. TRIGA	1,000	Argon-41 Particulate	2.41 0.001
20. TRIGA	1,000	Argon-41	2.6
21. TRIGA	1,000	Argon-41	1.8
22. TRIGA	1,000	Argon-41	1.231
23. TRIGA	1,000	Argon-41	1.0
24. TRIGA	250	Argon-41	0.003
25. TRIGA	250	Argon-41	0.016
26. TRIGA	250	none	0.0
27. TRIGA	250	Argon-41	0.06
28. TRIGA	250		N/A
29. TRIGA	250		N/A
30. TRIGA	250	None	0.0

See footnote at end of table.

Table 3.1-1. Radionuclide emissions from research and test reactors (Continued)

Design type	Power (kW)	Radionuclide	Emissions (Ci/y)
31. TRIGA	250	Argon-41	0.002
32. TRIGA	250		N/A
33. TRIGA	250	Tritium	0.002
34. TRIGA	250	none	0.0
35. Pool	200	Argon-41	3.1
36. Graphite/water	100	Argon-41	33
37. Light water	100		N/A
38. TRIGA	100	Argon-41	0.001
39. TRIGA	100		N/A
40. Graphite/water	100	Argon-41	68.2
41. Graphite/water	100	Argon-41	113
42. Graphite/water	100	Argon-41	17
43. TRIGA	18	Argon-41	0.3
44. Special	10	none	0.0
45. TRIGA	10	none	0.0
46. Graphite/water	10		N/A
47. Pool	10		N/A
48. Pool	10		N/A
49. Pool	10		N/A
50. Homogeneous	3	none	0.0
51. Pool	1.0		N/A
52. Special	1.0		N/A
53. Special	0.1	none	0.0
54. Tank	0.1		N/A
55. Homogeneous	0.015	none	0.0
56. Homogeneous	0.01	none	0.0
57. Homogeneous	0.01	Krypton-85	3E-8
58. Homogeneous	0.006		N/A
59. Homogeneous	0.005	none	0.0
60. Homogeneous	0.005	none	0.0
61. Homogeneous	0.0001	none	0.0
62. Homogeneous	0.0001		N/A
63. Homogeneous	0.0001	none	0.0
64. Tank	0.0001		N/A
65. Homogeneous	0.0001	none	0.0
66. Homogeneous	0.0001		N/A
67. Homogeneous	0.0001		N/A
68. Pool	0.0001		N/A
69. Pulse	N/A	none	0.0
70. Pulse	N/A	Argon-41	13.31

N/A Not available.

Table 3.1-2. Reference facility

Parameter	Value
Type	Heavy water reflected university reactor
Power level	5,000 KW
Stack height	50 meters
Emissions	
Argon-41	9700 Ci/y
Tritium	8 Ci/y

Table 3.1-3. Radiation dose rates from radionuclide emissions from the reference facility

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Whole body	1.0	343

Table 3.1-4. Fatal cancer risks due to radionuclide emissions from the reference facility

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Research and test reactor	2E-5	0.1

3.2 Accelerators

3.2.1 General Description

Accelerators are devices for imparting high kinetic energies to charged particles (such as electrons, alpha particles, protons, and deuterons) by electrical or magnetic fields. In a typical operation, the accelerated particles travel in an evacuated tube or enclosure. The particles impinge on a metallic or gaseous target, producing secondary radiation.

There are three basic accelerator designs, categorized according to the means used to achieve the particle velocity: (1) constant direct current (DC) field machines, (2) incremental acceleration machines, and (3) magnetic field accelerators.

Constant DC field machines (also called "Potential-drop" machines) operate at very high voltages, establishing an electric field of constant strength through which charged particles are accelerated toward the target. These accelerators are named according to the power supply used to generate the high DC voltage. The principal design types are the Van de Graaff, Cockcroft-Walton, Dynamitron, resonant transformer and insulating core transformer.

Incremental acceleration machines are accelerators whose electric field strength varies with time. This type of accelerator increases particle velocity in a nonlinear manner as the particle moves through the varying field. The principal design types are the linear accelerator (linac) and the cyclotron.

A magnetic field accelerator uses a time-varying magnetic field to generate an electric field which accelerates the particles. The only current example of this category is the betatron, which is used to accelerate electrons.

Accelerators have a variety of applications, including radiography, activation analysis, food sterilization and preservation, industrial processing, radiation therapy, and research. In 1977 the Bureau of Radiological Health (BRH78) estimated that there were over 1100 accelerators in use in this country, not including Federally-owned accelerators. All of the very high energy physics research accelerators are owned by the Department of Energy and are briefly discussed in Chapter 2.

Of the total number of accelerators in use, the percentage of each design types is as follows: linacs, 50 percent; neutron generators (of several different designs), 17 percent; Van de Graaff, 15 percent;

resonant and insulating core transformers, 6 percent; betatrons, 6 percent; cyclotrons, 3 percent; Cockcroft-Walton, 3 percent. Linacs are the most widely used machines, about 70 percent being used in medical applications.

3.2.2 Process Description

Radioactive emissions associated with accelerator operation are produced by two principal mechanisms: (1) the activation of air by accelerated particles or secondary radiation, resulting in radioactive carbon, nitrogen, oxygen, or argon; and (2) the loss of radioactive material (most frequently tritium) from a target into the air.

The principal air activation reactions are shown in Table 3.2-1. The formation of carbon-11, nitrogen-13, and oxygen-15 requires, at a minimum, certain threshold energies which are also listed in Table 3.2-1. These products would not be formed by accelerators which operate at low energies (typically, under 10 MeV).

Carbon-14 and argon-41 are produced by reactions involving the absorption of a neutron. The amount of radionuclides formed is in direct proportion to the neutron flux around the accelerator.

3.2.3 Control Technology

Control of air-activation products with short half-lives can be accomplished by delaying the venting of the room air. Several accelerators are capable of such holdup, but they do not use holdup as an emission control during normal operations. There are no controls in use to reduce tritium emissions.

3.2.4 Radionuclide Emissions

Table 3.2-2 gives estimated annual radioactive emissions from three reference facilities. These values were taken from a previous EPA study of these facilities (EPA79).

3.2.5 Reference Facilities

Table 3.2-3 shows the operating parameters of the three reference accelerator facilities. The three facilities are typical of accelerators in use today. The reference facility emissions are taken from Table 3.2-2.

3.2.6 Health Impact Assessment

The estimated annual radiation doses from the three reference particle accelerators are shown in Table 3.2-4. The individual lifetime risks and expected fatal cancers are shown in Table 3.2-5.

3.2.7 Total Health Impact

The estimated total number of fatal cancers caused by all non-DOE accelerators is 7E-5 per year. This was calculated using the information in Table 3.2-5 and assuming that there are currently 1,500 such accelerators in operation and that 50 percent of them are linacs, 3 percent are cyclotrons, and 47 percent are constant DC field machines. The three reference facilities were assumed to be representatives of these three categories.

3.2.8 Existing Emission Standards and Air Pollution Controls

Accelerators are regulated by the individual States. All of the States have adopted the Radiological Concentration Guides given by the Nuclear Regulatory Commission in 10 CFR Part 20. These guides do not cover isotopes with very short half-lives. The guides for carbon-14, argon-41, and tritium are: 1E-7 microcuries/ml, 4E-8 microcuries/ml and 2E-7 microcuries/ml, respectively.

3.2.9 Supplemental Control Technology

Emissions of the air activation products could be reduced by the use of holdup systems. However, tritium, which dominates the total health effects, cannot be controlled by holdup due to its 12 year half-life. Experimental tritium control systems include adsorption on charcoal and cryogenic distillation, but these systems have not been commercially demonstrated.

Table 3.2-1. Nuclear reactions responsible for some airborne radioactivity

Reaction	Parent nuclide	Radionuclide produced	Threshold energy (MeV)	Half-Life
(γ,n)	Nitrogen-14	Nitrogen-13	10.5	10 m
(γ,n)	Oxygen-16	Oxygen-15	15.7	2 m
(γ,n)	Carbon-12	Carbon-11	18.7	20 m
(n,2n)	Nitrogen-14	Nitrogen-13	11.3	10 m
(n,2n)	Oxygen-16	Oxygen-15	18.0	2 m
(n,2n)	Carbon-12	Carbon-11	20.0	20 m
(n,p)	Nitrogen-14	Carbon-14	NA	5730 y
(p,pn)	Oxygen-16	Oxygen-15	10.0	2 m
	Nitrogen-14	Nitrogen-13	10.0	10 m
(n,α)	Oxygen-17	Carbon-14	NA	5730 y
(n,γ)	Argon-40	Argon-41	NA	1.9 h

NA Not applicable.

m minutes
h hours
y years

Table 3.2-2. Estimated annual emissions from typical particle accelerators (EPA79)

Radionuclide	100 MeV Cyclotron (Ci)	18 MeV Electron Linac (Ci)	6 MeV Van de Graaff[a] (Ci)
Carbon-11	2.0E-3		
Nitrogen-13	4.0E-2		
Oxygen-15	1.0		
Tritium			1
Carbon-14		1.0E-9	
Argon-41		1.0E-4	

[a] Tritium target used for neutron generation; release estimates include emissions from laboratory hoods due to tritium target handling operations.

Table 3.2-3. Reference accelerator facilities

Parameter	Value
Type of accelerator:	6 MeV Van de Graaff with tritium target--operating 3000 h/y 18 MeV electron linac operating 2000 h/y 100 MeV research cyclotron operating 1000 h/y
Emissions control:	None
Stack characteristics:	
Height	16.8 meters (roof type)

Table 3.2-4. Annual radiation doses due to radioactive emissions from typical accelerators (EPA80)

Type of accelerator	Maximum individual (mrem/y)	Population (person-rem/y)
6 MeV Van de Graaf	1.1E-4	5.9E-4
18 MeV Electron linac	4.2E-8	3.1E-7
100 MeV Research cyclotron	9.6E-5	5.1E-6

Table 3.2-5. Individual lifetime risks and number of fatal cancers due to radioactive emissions from typical accelerators (EPA80)

Type of accelerator	Individual lifetime risk Maximum individual	Expected fatal cancers per year of operation (Fatal cancers)
6 MeV Van de Graaf	2E-9	1E-7
18 MeV Electron linac	6E-13	6E-11
100 MeV Research Cyclotron	1E-9	1E-9

REFERENCES

BRH78	Bureau of Radiological Health, 1978, Report of State and Local Radiological Health Programs, Fiscal Year 1977. HEW Pub.No. 78-8034, FDA, Department of Health, Education and Welfare, Rockville, Md. 20852.
EPA79	Environmental Protection Agency, A Study of Radioactive Airborne Effluents from Particle Accelerators, Technical Note, ORP/TAD-79-12, Washington, D.C., August 1979.
EPA80	Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States -- Preliminary Report, EPA 520/7-79-006, Office of Radiation Programs, EPA, Washington, D.C., Reprinted 1980.

3.3 Radiopharmaceutical Industry

3.3.1 General Description

Increasing medical and research demands for radioactive chemicals have resulted in the evolution of a large radiopharmaceutical industry. This industry comprises the suppliers that produce or package radiopharmaceuticals, the users of radiopharmaceuticals, and waste-receiving facilities. Suppliers include manufacturers and nuclear pharmacies. Manufacturers include companies that manufacture radionuclides for use as raw materials by other radiopharmaceutical companies, and companies that process radionuclides into radiopharmaceuticals and radioimmunoassay (RIA) kits (TRI79). Nuclear pharmacies obtain bulk amounts of radiopharmaceuticals and repackage them for distribution.

Users include hospitals and private physicians that dispense pharmaceuticals and medical and research laboratories that utilize RIA materials. Of all users, hospitals contribute the most airborne radioactivity because most nuclear medicine procedures are performed at hospitals.

Waste-receiving facilities that receive wastes from suppliers and users of radiopharmaceuticals have the potential to produce airborne emissions of radionuclides. These facilities include incinerators and sewage treatment plants. It is estimated that more than 90 percent of the airborne radioactive emissions from waste-receiving facilities are from sewage treatment plants (TRI79).

Suppliers

Industrial suppliers produce 65 different, generally-used radionuclides (EPA80). Major suppliers of radiopharmaceuticals and medical isotopes are listed in Table 3.3-1 (TRI79). This list does not include nuclear pharmacies.

Iodine-131, iodine-125, xenon-133, and technetium-99m have been identified as the radionuclides having the greatest potential for release as airborne effluents from radiopharmaceutical suppliers (Le79).

Users

Radionuclides are extensively used for medical diagnosis, therapy, and research. The number of medical facilities using radioactive materials has grown from 38 in 1946 to over 10,000 NRC and Agreement State licensees in 1977. In 1977 alone, it is estimated that there were 15 million in-vivo and 20 million in-vitro therapeutic and diagnostic procedures performed at costs of about $48 million for in-vivo sales and about $105 million for in-vitro sales (TRI79). Radionuclides used in diagnostic and therapeutic procedures are listed in Table 3.3-2 (EPA80).

Table 3.3-1. Major suppliers of radiopharmaceuticals and medical isotopes, excluding nuclear pharmacies (TRI79)

Location	Supplier	Product
California		
Emeryville	Medi-Physics, Inc. (home office)	Indium-111, Iodine-123, Gallium-67, Rubidium-81/ Krypton-81m generators, Xenon-133, Technetium-99m.
Glendale	Medi-Physics, Inc.	Technetium-99m-labeled compounds.
Vallecitos	General Electric Company	Xenon-133.
Van Nuys	Nuclear Med. Svcs.,Inc.	Groups I, II, & IV(a).
San Ramon	Gammaceutics	Iodine-123
Davis	University of California	Iodine-123
Irvine	ICN Pharmaceuticals	RIA kits(b).
Richmond	Bio-Rad Laboratories	Iodine-125, Cobalt-57, RIA kits.
Florida		
Miami Lakes	Medi-Physics, Inc.	Technetium-99m-labeled compounds.
Georgia		
East Point	Medical Research Foundation, Inc.	Yttrium-90 microspheres.
Illinois		
North Chicago	Abbott Laboratories	Molybdenum-99/ Technetium-99m generators. Kits for preparation of Tc-99m labeled compounds.
Arlington Heights	Amersham Corporation	Cobalt-58 as cyanocobalamin, Selenium-75 as selenomethionine, Iodine-125 as fibrinogen.
Rosemont	Medi-Physics, Inc.	Technetium-99m as pertechnetate. Kits for preparation of Tc-99m labeled material.

See footnotes at end of table.

Table 3.3-1. Major suppliers of radiopharmaceuticals and medical isotopes, excluding nuclear pharmacies (TRI79)--continued

Location	Supplier	Product
Indiana		
Indianapolis	Bio-Dynamics	Kits for preparation of Tc-99m-labeled DTPA[c], and pyrophosphate.
Elkhart	Miles Laboratories Ames Company	Iodine-125 RIA kits.
Massachusetts		
Billerica	Cambridge Nuclear Radiopharmaceutical Corp.	Kits for preparation of Tc-99m-labeled pyrophosphate, DTPA.
	New England Nuclear Corp.	Thallium-201, Gallium-67, Iodine-131, Iodine-125 Selenium-75, Phosphorus-32, Mo-99/Tc-99m generators.
Attleboro Falls	Gamma Diagnostics Lab.	Tc-99m as pertechnetate, sulfur colloid, aggregated albumin.
Boston	New England Nuclear Corp. Radiopharmaceutical Div.	Organic compounds labeled with Tritium, Carbon-14, Phosphorus-32, and Sulfur-35
Bedford	CIS Radiopharmaceuticals, Inc.	Kits for preparation of Tc-99m-labeled DTPA, albumin, pyrophosphate, sulfur colloid, and aggregated albumin.
Minnesota		
St. Paul	Minnesota Mining & Manufacturing Co.	Kits for preparation of Tc-99m-labeled materials. Ytterbium-169 as DTPA.
Missouri		
St. Louis	Mallinckrodt, Inc. Diagnostic Products Div.	Kits for preparation of Tc-99m-labeled materials; Chromium-51, Iron-59, Mercury-197, Iodine-125, Phosphorus-32, Selenium-75, Mo-99/Tc-99m generators.
Columbia	University of Missouri	Molybdenum-99 (as raw material).

See footnotes at end of table.

Table 3.3-1. Major suppliers of radiopharmaceuticals and medical isotopes, excluding nuclear pharmacies (TRI79)--continued

Location	Supplier	Product
New Jersey		
Princeton	E.R. Squibb & Sons, Inc.	Kits for preparation of Tc-99m-labeled materials, Gold-198, Chromium-51, Mercury-197, Iodine-131, Iodine-125, Phosphorus-32, Selenium-75, Strontium-85, Cobalt-60, Mo-99/Tc-99m generators.
S. Plainfield	Medi-Physics, Inc.	Iodine-123, Gallium-67, Tc-99m, Indium-111, Rb-81/Kr-81m generators.
Ohio		
Cincinnati	Procter and Gamble Co.	Kits for preparation of Technetium-99m, disodium etidronate.
New York		
Tuxedo	Union Carbide Corp.	Tc-99m, Xenon-133, Iodine-131, Iodine-125, Mo-99/Tc-99m generators.
Virginia		
Richmond	Va. Commonwealth Univ.	Kits for preparation of Tc-99m-labeled materials, sulfur colloid, aggregated albumin

---

(a)See 10 CFR 35.100, Schedule A.
(b)RIA Radioimmunoassay.
(c)DTPA Diethylenetriamine pentaacetic acid.

Iodine-131, iodine-125, xenon-133, and technetium-99m have been identified as having the greatest potential for release as airborne effluents from medical facilities. Although releases are much more likely if the nuclide is easily volatilized, technetium-99m is included because of the large quantities used in hospitals. Xenon is used primarily in diagnostic procedures with approximately 62 percent used in large hospitals (over 500 beds).

Table 3.3-2. Major radiopharmaceuticals and their uses (EPA80)

Radionuclide	Use
Phosphorus-32	Bone marrow therapy
Gallium-67	Tumor localization
Rubidium-81	Myocardial imaging
Technetium-99m	Bone imaging, brain imaging, liver imaging, lung perfusion, myocardial imaging, blood pool, renograms, thyroid imaging, thyroid uptake renal imaging
Iodine-123	Thyroid imaging Thyroid uptake
Iodine-125	Renograms
Iodine-131	Renal imaging, renograms, thyroid imaging, thyroid uptake, tumor localization and therapy
Xenon-133	Lung ventilation
Mercury-203	Renograms
Thallium-201	Myocardial imaging

Iodine is used for diagnostic and therapeutic procedures with approximately 60 percent used in large hospitals. Estimated quantities of radionuclides received and used by hospitals in 1977 are listed in Table 3.3-4.

Table 3.3-4. Estimated quantities of radionuclides received and used by hospitals, 1977

Radionuclide	Quantity (Ci)	
	Received	Used
Iodine-131	900-1500	300-1350
Xenon-133	2,700-3,300	1,600-2,000
Technetium-99m	26,000-34,000	15,000-30,000

Waste-Receiving Facilities

Most of the radionuclides used at medical facilities are released via the liquid pathway to the sanitary sewer system. When sewage and sludge containing this material are treated in a sewage treatment plant, radionuclides may be emitted into the air.

Iodine-131, iodine-125, and technetium-99m have the greatest potential for release as airborne effluents from sewage treatment plants (TRI79).

3.3.2 Process Description

Radionuclides used in the radiopharmaceutical industry are produced by irradiation of target materials (or fuel) in a reactor or accelerator, and by radioisotope generators.

Suppliers

Radionuclide manufacturing involves complex chemical processes that have the potential for releasing radioactive materials to the environment. Most radionuclides produced for use in the industry are made in nuclear reactors by one of the reactions shown in Table 3.3-5. The most common of these is the neutron-gamma reaction because many elements capture neutrons easily. It is estimated that reactor-produced isotopes account for 60 to 80 percent of the market (TRI79).

Table 3.3-5. Nuclear reactions used in radioisotope production

Reaction	Examples
(1) Neutron-gamma (n,γ)	$^{59}Co + n \rightarrow {}^{60}Co + \gamma$
(2) Neutron-proton (n,p)	$^{32}S + n \rightarrow {}^{32}P + p$
(3) Neutron-alpha (n,α)	$^{35}Cl + n \rightarrow {}^{32}P + \alpha$

In a reactor, the main steps in radionuclide production are as follows (EPA80):

1. A suitable target is prepared and irradiated with neutrons.

2. The irradiated target is processed by dissolution or by more complicated separations (including ion exchange, precipitation, and distillation) to remove undesirable impurities, or to concentrate the product nuclide.

3. Radionuclides are placed in inventory, dispensed, and packaged for shipment.

Many radionuclides are produced in particle accelerators, such as the cyclotron. Amounts of radioactive materials produced in accelerators are smaller than amounts produced in reactors.

The cyclotron can be used to produce nuclides having decay characteristics that are preferable to other isotopes of the same element that are produced in reactors and isotopes of elements for which no reactor-produced nuclides exist. Examples of accelerator-produced radionuclides are iodine-123, iron-52, mercury-199m, carbon-11, nitrogen-13, and oxygen-15.

Typical nuclear pharmacy production activities include processing, mixing or compounding, and distribution of prepared radiopharmaceuticals.

There is a growing trend for nuclear pharmacies to operate radioisotope generators for the production of certain radionuclides having short half-lives; for example, technetium-99m. Radioisotope generators make nuclides with short half-lives available at long distances from the source of production. These generators consist of a longer-lived parent nuclide that produces the short-lived daughter as it decays. In the generator, the daughter nuclide is chemically separated at intervals, leaving the parent nuclide to generate more of the daughter.

Users

In hospitals, radionuclides are generally handled in solid or liquid form, except for some radioactive gases, notably xenon. This tends to decrease the likelihood of release of airborne effluents.

Therapeutic iodine-131, generally in the form of sodium iodide, is readily volatilized, and can become an airborne contaminant when used in some therapeutic procedures.

Xenon-133 can also be released as an airborne effluent. Because of a low biological half-life, relatively large amounts are administered for lung-imaging procedures. Following administration, patients exhale xenon-133 gas into a spirometer. The exhaust from this instrument exits the hospital through a roof vent, with or without treatment.

Technetium-99m is used in large quantities in hospitals, and is obtained directly from the manufacturer or from the nuclear pharmacy where it is produced in a radioisotope generator from molybdenum-99. Although not a gaseous or volatile isotope, technetium-99m is a potential airborne effluent because of the quantities used in nuclear medicine procedures.

Waste-Receiving Facilities

Radionuclide releases at sewage treatment plants depend upon several factors. The chemical and physical properties of wastewater and sludge influence the potential amount of radioactivity released; e.g., the potential for release is greater at points in the treatment process where wastewater pH is acidic. Other factors that affect radionuclide releases include decay losses, evaporative losses, solids removal, degree of system retention, and dilution.

Sludge treatment processes (drying and incineration) are the greatest sources of radionuclide emissions from sewage treatment plants because the high temperatures employed in these processes (typically 725°C) volatilize iodine and technetium. In addition, sludge incineration has the smallest time delay compared with other sludge treatment processes, and the greatest potential for release of particulates caused by mechanical agitation of ash and combustion gases in the incinerator (TRI79).

It is estimated that approximately 21 percent of the sewage treatment facilities in the U.S. employ incineration or pyrolysis for sludge treatment (EPA80). In a treatment facility, sludge is typically concentrated in settling tanks before it is concentrated further in another sludge treatment process (e.g., centrifugation). Following this process, the sludge is conveyed to an incinerator and burned at temperatures up to 815°C.

3.3.3 Control Technology

Types of effluent controls employed by producers of radiopharmaceuticals depend on the type and amount of each nuclide handled in the facility (Le80). All suppliers handling large amounts of iodine, and some dealing in smaller quantities, handle this material in hot cells or fume hoods that exhaust through HEPA and/or activated carbon filters before release through a roof-mounted vent stack. Some suppliers that handle small amounts of radioiodine, or only nonvolatile nuclides such as molybdenum and technetium, use no filters, or only HEPA filters on fume hoods and building ventilation exhausts. This exhaust is usually released from a short vent stack (2 to 3 m high) on top of the building (TRI79). Xenon manufacturers generally use ventilation controls only. One large producer controls radioactive xenon emissions by cryogenically liquefying hot cell off-gas, and holding it for decay.

Small hospitals (less than 300 beds) generally operate with no effluent controls because the total activity of the principal isotope used (technetium-99m) is low, and because it is handled in solution. Hospitals in the medium-size range (300 to 500 beds) generally use xenon traps and unfiltered fume hoods, but may use controls similar to those of the larger hospitals if large amounts of activity are handled daily. Some hospitals capture patient xenon exhalations for holdup in retention bags before release. Other medium-size hospitals may have no controls if radiopharmaceuticals are administered infrequently, or if their emissions meet NRC MPC requirements without controls. Larger hospitals (over 500 beds) generally use controls similar to those used by suppliers because of the large amounts of activity handled, and because of the variety of radioisotopes used. Controls at large hospitals range from fume hoods with HEPA and activated carbon filters and xenon traps or retention bags to unfiltered fume hoods and no xenon controls (TRI79).

3.3.4 Radionuclide Emission Measurements

Suppliers

Data presented in this section are drawn from emissions data submitted to EPA by medical isotope producers and from reports of surveys conducted at several radiopharmaceutical manufacturing firms. The emissions data represent airborne releases from normal operations as measured by company-owned or contractor monitoring systems. Average annual emissions of six radiopharmaceutical suppliers are listed in Table 3.3-6.

The NRC conducted a survey of over 3000 by-product material licensees in late 1980 to collect annual radioactive effluent emissions data (NRC81). Table 3.3-7 summarizes emissions data for 385 industrial facilities that manufacture radionuclides who responded to the survey.

Table 3.3-6. Radionuclide emissions from six major radiopharmaceutical producers (Co82, EPA80, Fra82, Frb82, Roa82, Rob82)

Producing Plant	Emissions (Ci/y)		
	Iodine-125	Iodine-131	Technetium-99m
A	1.8E-2	3.9E-4	-
B	2.2E-6	-	-
C	-	-	4.14E-3
D	-	-	4.5E-3
E	1.0E-2	7.6E-2	-
F	2.6E-3	3.1E-2	-

Table 3.3-7. Summary of reported atmospheric emissions of radionuclides from 385 industrial facilities (NRC81)

Source	Number of facilities using nuclide	Number of facilities reporting releases	Emissions (Ci/y)		
			Mean	Maximum	Minimum
Iodine-131	11	4	1.8E-4	4.6E-4	3.0E-5
Iodine-125	55	25	1.7E-3	2.0E-2	3.0E-8
Xenon-133	6	4	7.0	2.3E+1	2.0E-2
Molybdenum-99	4	4	8.3E-6	3.0E-5	1.5E-7
Technetium-99m	2	1	3.2E-6	3.2E-6	3.2E-6

Users

The survey conducted by the NRC (NRC81) also included radioactive emissions data for 860 government and public medical facilities. These data are summarized in Table 3.3-8.

Sewage Treatment Plants

Radioactive airborne emissions resulting from sludge drying and incineration at a sewage treatment plant were studied (TRI79) and estimated to be 5.0E-4 Ci/y for iodine-131 and 8.0E-4 Ci/y for technetium-99m. This report also estimated that about 4000 sewage treatment plants in the United States employ these sludge treatment processes.

Table 3.3-8. Summary of reported atmospheric emissions of radionuclides from 860 government and public medical facilities (NRC81)

Source	Number of facilities using nuclide	Number of facilities reporting releases	Emissions (Ci/y) Mean	Emissions (Ci/y) Maximum	Emissions (Ci/y) Minimum
Iodine-131	346	25	2.9E-3	5.0E-2	2.0E-8
Iodine-125	270	19	1.7E-3	9.5E-3	1.0E-8
Xenon-133	229	142	4.6E-1	6.4	2.0E-5
Molybdenum-99	268	3	1.0	3.0	1.0E-8
Technetium-99m	73	2	2.8E-1	5.0E-1	5.2E-2

3.3.5 Reference Facilities

Radiopharmaceutical Supplier Facility

The radiopharamaceutical supply industry can be characterized as generally urban, with suppliers located near their major users, hospitals (TRI79). Table 3.3-9 describes the parameters of a typical radiopharmaceutical production plant. These parameters were used to estimate health impacts resulting from emissions from the reference facility.

The typical facility produces technetium-99m, xenon-133, iodine-131, iodine-125, and molybdenum-99/technetium-99m generators (EPA80). Airborne releases are discharged from a single stack. Atmospheric emissions from the reference facility are listed in Table 3.3-10. Emissions from the reference facility were chosen as equal to emissions from facilities having the highest values listed in Tables 3.3.6 and 3.3.7.

Emissions from the reference facility are controlled by charcoal beds and HEPA filters.

User Facility

Parameters that describe the reference medical facility are listed in Table 3.3-9. These parameters represent a typical large hospital. It is assumed that the hospital has nuclear medicine capabilities, and administers an average of 0.5 curies per year of iodine-131, 0.05 curies per year of iodine-125, and 25.0 curies per year of xenon-133.

Table 3.3-9. Reference facilities of typical suppliers and users of radiopharmaceuticals

Parameter	Value
Supply Facility	
Product line:	Iodine-131, iodine-125, xenon-133, technetium-99m, molybdenum-99/ technetium-99m generators.
Emission controls:	Activated carbon/HEPA filters with release through a single elevated stack
Stack parameters:	Height: 15 meters.
User Facility	
Size:	500+ beds
Volume of administrations:	Iodine-131, 0.5 Ci/y Iodine-125, 0.05 Ci/y Xenon-133, 25.0 Ci/y
Emission controls:	Exhaust hoods with carbon and HEPA filters. Release through building ventilation roof vents. Vent height: 10 m.
Sewage Treatment Plant	
Process:	Sludge drying and incineration

Estimated annual atmospheric emissions from the reference medical facility are listed in Table 3.3-10. These emission estimates represent maximum emission levels for I-131, I-125, and Xe-133 from sources described in Table 3.3-8. Although molybdenum-99 and technetium-99m are used at the reference facility, releases are assumed to be zero because, as indicated in Table 3.3-8, airborne releases are rarely observed for these nuclides.

Sewage Treatment Facility

The reference sewage treatment plant dries and incinerates sludge. Atmospheric emissions from a typical sewage treatment plant that employs these processes are listed in Table 3.3-10. These emission estimates are based on a study of airborne emissions from a sewage treatment plant (TRI79).

Table 3.3-10. Radionuclide emissions from reference radiopharmaceutical industry facilities

Source/Radionuclide	Emissions (Ci/y)
Supply Facility	
Iodine-125	2.0E-2
Iodine-131	7.6E-2
Xenon-133	2.3E+1
Technetium-99m	4.5E-3
User Facility	
Iodine-125	9.5E-3
Iodine-131	5.0E-2
Xenon-133	6.4
Sewage Treatment Plant	
Iodine-131	5.0E-4
Technetium-99m	8.0E-4

3.3.6. Health Impact Assessment of Reference Radiopharmaceutical Industry Facilities

The estimated annual radiation doses from radionuclide emissions from the reference radiopharmaceutical supply facility, medical facility, and sewage treatment plant are listed in Table 3.3-11. These estimates are for the near suburbs of a large midwest city with a regional population of 2.5 million (Reference Site B). The maximum exposed individuals are located 500 meters from the supply facility, 500 meters from the medical facility, and 500 meters from the sewage treatment plant.

Table 3.3-12 presents estimates of the maximum individual lifetime risks and the number of fatal cancers to the regional population from these doses.

3.3.7 Total Health Impact of the Radiopharmaceutical Industry

For all segments of the radiopharmaceutical industry, the estimated total health impact is 9E-4 fatal cancers per year. The following analysis details how this estimate was obtained.

Suppliers

The estimated total health impact caused by all radiopharmaceutical suppliers is based on the assumptions that (1) emissions of

Table 3.3-11. Radiation dose rates from radionuclide emissions from the reference radiopharmaceutical industry facilities

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Radiopharmaceutical supplier		
Thyroid	4.7E-1	3.3
Medical facility		
Thyroid	3.6E-1	1.7
Sewage treatment plant		
Thyroid	8.0E-4	7.4E-3

Table 3.3-12. Fatal cancer risks due to radionuclide emissions from the reference radiopharmaceutical industry facilities

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Radiopharmaceutical supplier		
	2E-7	2E-5
Medical facility		
	2E-7	6E-6
Sewage treatment plant		
	2E-10	2E-8

I-125, I-131, Xe-133, and Tc-99m reported for industrial facilities in a survey by NRC (NRC81) are from radiopharmaceutical suppliers; and (2) the number of industrial licensees in non-agreement states, for which data were available, is approximately equal to the number of licensees in agreement states.

Data presented in the NRC survey (NRC81) showed that approximately 15% of industrial licensees in the survey handled I-125, 3% handled I-131, and less than 2% handled Xe-133 and Tc-99m. Based on these figures and the above assumptions, the total numbers of suppliers in the U.S. handling I-125 and I-131 are 328 and 66, respectively. Although the number of suppliers handling Xe-133 and Tc-99m would be less than 44, this figure will be used for estimation purposes.

Assuming that available average emissions data (Tables 3.3-6 and 3.3-7) are typical of the entire industry, total annual emissions from all radiopharmaceutical suppliers are as follows: I-125, 0.82 Ci/y; I-131, 0.99 Ci/y; Xe-133, 310 Ci/y; and Tc-99m, 0.13 Ci/y.

Based on these emissions, releases from the reference facility (Table 3.3-10) are 2.4% of the national total for I-125, 7.7% for I-131, 7.4% for Xe-133, and 3.5% for Tc-99m. Assuming that the reference facility also causes equal percentages of total health impact, the impact from all radiopharmaceutical suppliers is 3E-4 fatal cancers per year. Contributions to this figure from each radionuclide are as follows: I-125, 1E-4; I-131, 4E-5; Xe-133, 1.7E-4; and Tc-99m, 3E-8.

Users

Assuming that the number of medical facility licensees in non-agreement and agreement states is approximately equal, data in the NRC survey (NRC81) indicate that approximately 1,100 facilities in the U.S. use I-125, 1,200 facilities use I-131, and 800 use Xe-133.

If the average emissions listed in Table 3.3-8 are assumed to be typical of all medical facilities, total annual emissions from all medical facilities are as follows: I-125, 1.9 Ci/y; I-131, 3.5 Ci/y; and Xe-133. 370 Ci/y.

Emissions from the reference facility contribute 0.5% of the total I-125 emission, 1.4% of the total I-131 emission, and 1.7% of the Xe-133 emission. Assuming that the reference facility contributes equal percentages to the total health impact, the impact from all medical facilities is 5E-4 fatal cancers per year. Contributions to this figure from each radionuclide are as follows: I-125, 2E-4; I-131, 1E-4; and Xe-133, 2E-4.

Sewage Treatment Plants

It has been estimated that approximately 4000 sewage treatment plants in the U.S. employ sludge incineration or pyrolysis (TRI79).

Assuming that emissions from the reference facility are typical of emissions from all sewage treatment plants that incinerate sludge, the total annual emissions of I-131 and Tc-99m are 2.0 Ci/y and 3.2 Ci/y, respectively.

The total health impact from all sewage treatment plants is 6E-5 fatal cancers per year, which reflects contributions of 6E-5 and 8E-7 from I-131 and Tc-99m, respectively.

3.3.8 Existing Emission Standards and Air Pollution Controls

Suppliers and users of radiopharmaceuticals are NRC licensees and are therefore required to limit effluent releases to unrestricted areas to the maximum permissible concentrations of 10 CFR 20, Appendix B, Table II. There are no radionuclide emission standards for sewage treatment plants.

3.3.9 Supplemental Control Technology

Suppliers

Existing emission controls typically employed at supplier facilities (HEPA and carbon beds/filters) effectively remove particulates and radioiodines, but not radioactive noble gases.

Supplemental methods for controlling noble gas releases include cryogenic systems and hold-up tanks. The performance of cryogenic systems in large commercial facilities has not yet been demonstrated, nor is there an approved disposal method for the concentrated, potentially long-lived, high-activity wastes that these systems produce (TRI79). Hold-up tanks are best suited to effluents with low release rates which contain short-lived noble gases.

Because the entire volume of effluent must be retained to allow for decay, hold-up is feasible only at very low release rates. Since exhaust rates at supplier facilities typically are in the range of 10^5 to 10^6 liters per minute, the tanks required for hold-up would be too large and too costly to be practical. Implementation of supplemental controls for noble gas control at supply facilities is, therefore, not currently practicable.

Users

Xenon retention bags, which are now in use at some medical facilities, are a feasible means of reducing radioactive emissions because of low release rates of xenon-133. The costs and risk reductions achieved by adding supplementary controls to capture patient xenon exhalations at the reference medical facility are shown in Table 3.3-13.

Sewage Treatment Plants

Sewage treatment plants employing sludge incineration typically use dry cyclones and wet scrubbers to control gaseous and particulate emissions. Supplementary controls consist of charcoal filters to reduce iodine emissions and HEPA filters to reduce particulate emissions of technetium. HEPA filters are required upstream of the charcoal filters to prevent plugging.

Costs and risk reductions achieved by adding these supplementary controls to the incinerator stacks of the reference sewage treatment plant to reduce iodine-131 and technetium-99m emissions are shown in Table 3.3-13.

Table 3.3-13. Costs and risk reductions of adding supplemental controls to reference radiopharmaceutical industry facilities

Type of control	Level of control	Annual[a] cost ($1000)	Fatal cancer risks: Individual lifetime risk	Fatal cancer risks: Fatal cancers/y
Medical facility				
No xenon controls[b]	0	-	2E-7	6E-6
Add retention bags or xenon traps	99.9	25.0	1E-7	3E-6
Sewage treatment plant				
Dry cyclone and scrubber[b]	90[c]	-	2E-10	2E-8
Add HEPA filter with preheater and charcoal filter	99[c] 90[d]	50.0	2E-11	2E-9

[a] Does not include capital costs.
[b] Typical existing controls.
[c] Particulates.
[d] Iodines.

REFERENCES

Co82 Cole L. W., Environmental Survey of the Manufacturing Facility, Medi-Physics, Inc., Arlington Heights, Illinois, Oak Ridge Associated Universities, Oak Ridge, Tennessee, January 1982.

EPA80 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States--Preliminary Report, EPA 520/7-79-006, Office of Radiation Programs, EPA, Washington, D.C., Reprinted 1980.

Fra82 Frame P. W., Environmental Survey of the New England Nuclear Corporation, Billerica, Massachusetts, Oak Ridge Associated Universities, Oak Ridge, Tennessee, April 1982.

Frb82 Frame P. W., Environmental Survey of the New England Nuclear Corporation, Boston, Massachusetts, Oak Ridge Associated Universities, Oak Ridge Tennessee, April 1982.

Le79 Leventhal L., et al., Radioactive Airborne Effluents from the Radiopharmaceutical Industry, in Proceedings of the Health Physics Society, 24th Annual Meeting, Philadelphia, Pa., 1979.

Le80 Leventhal L., et al., A Study of Effluent Control Technologies Employed by Radiopharmaceutical Users and Suppliers, in: Book of Papers, International Radiation Protection Association, 5th International Congress, Volume II, Jerusalem, Israel, 1980.

NRC81 Nuclear Regulatory Commission, A Survey of Radioactive Effluent Releases from Byproduct Material Facilities, NUREG-0819, Office of Nuclear Material Safety and Safeguards, NRC, Washington, D.C., 1981.

Roa82 Rocco B. P., Environmental Survey of the Medi-Physics Facility, South Plainfield, New Jersey, Oak Ridge Associated Universities, Oak Ridge, Tennessee, January 1982.

Rob82 Rocco B. P., Environmental Survey of the E. R. Squibb and Sons Facility, New Brunswick, New Jersey, Oak Ridge Associated Universities, Oak Ridge Tennessee, March 1982.

TRI79 Teknekron Research, Inc., Information Base (Including Sources and Emission Rates) for the Evaluation and Control of Radioactive Materials to Ambient Air, Interim Report, Volume I, EPA Contract No. 68-01-5142, July 1979.

3.4 Department of Defense Facilities

3.4A Armed Forces Radiobiology Research Institute (AFRRI)

3.4A.1 General Description

The Armed Forces Radiobiology Research Institute (AFRRI) operates a TRIGA Mark-F pool-type thermal research reactor, and a linear accelerator (linac) in support of Department of Defense radiation research. Most of this research involves studies of medical effects of nuclear radiation and the effects of transient radiation on electronics and other equipment.

The AFRRI reactor is licensed by the NRC to operate at steady-state power levels up to 1.0 MW (thermal). This reactor is also capable of pulse operations, and can produce a 10 msec pulse of about 2500 MW (thermal) at peak power.

AFRRI's linac typically operates in the 18 to 20 MeV energy range but is capable of operating at energies up to 30 MeV.

AFRRI is located on the grounds of the National Naval Medical Center in Bethesda, Maryland, approximately 20 kilometers northwest of Washington, D.C.

3.4A.2 Process Description

The AFRRI reactor and accelerator are used for Department of Defense radiation research. This research includes medical effects of nuclear radiation, radiobiology, and radioisotope production. AFRRI facilities have also been used to support Federal criminal investigations, studies of transient radiation effects on electronics, and artifact analysis (Sh81).

The reactor core, which is cooled by natural convection, is located under about 5 m of water, and is movable laterally within an open cloverleaf-shaped pool. Pool dimensions are 4.2 m across the major lobes, 3.9 m across the minor lobes, and 5.8 m deep.

Exposure facilities available to users include two separate exposure rooms, a pneumatic tube transfer system, the pool itself, and an in-core experiment tube.

Reactor fuel is 8.5 weight percent uranium which has been enriched to 20 percent uranium-235.

3.4A.3 Control Technology

Emissions from the AFRRI reactor and accelerator are released to the atmosphere through a common stack atop the AFRRI building. Particulate emissions are controlled by a roughing filter, prefilter, and HEPA filter.

3.4A.4 Radionuclide Emissions Measurements

Annual airborne radionuclide emissions for AFRRI are shown in Table 3.4A-1. These figures represent average annual emissions for 1981 and 1982.

Table 3.4A-1. Radionuclide emissions from the Armed Forces Radiobiology Research Institute

Source	Radionuclide	Emissions[a] (Ci/y)
AFRRI stack	Argon-41	1.3
AFRRI stack	Nitrogen-13, and Oxygen-15	3.5E-2

(a)Average annual emissions for 1981 and 1982.

3.4A.5 Health Impact Assessment of AFRRI

The estimated annual radiation doses resulting from radionuclide emissions from AFRRI are listed in Table 3.4A-2. The distance from the AFRRI facility to the nearest residence is approximately 200 meters. These estimates are for an urban site with a regional population of 2.5E+6 (Reference Site B). The maximum individual is located 500 meters from the AFRRI facility.

Table 3.4A-3 lists the estimated individual lifetime risks and the number of fatal cancers to the regional population from these doses.

3.4A.6 Existing Emission Standards and Air Pollution Controls

The AFRRI reactor is licensed by NRC and is therefore subject to the emission requirements of 10 CFR 20.106. This regulation places limits on air emissions to unrestricted areas. For argon-41, this limit is 4×10^{-8} microcuries per milliliter above background.

Table 3.4A-2. Radiation dose rates from radionuclide emissions from the Armed Forces Radiobiology Research Institute

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Total body	4.8E-3	1.7E-3

Table 3.4A-3. Fatal cancer risks due to radionuclide emissions from the Armed Forces Radiobiology Research Institute

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
AFRRI	1E-7	5E-7

3.4A.7 Supplemental Control Technology

There is no demonstrated treatment technology for control of emissions of argon-41 from reactors. Reduction of these emissions is best accomplished by work practice controls; i.e., reducing reactor operating time.

REFERENCES

Sh81 Sholtis, J. A. and Moore M. L., Reactor Facility, Armed Forces Radiobiology Research Institute, AFRRI Technical Report TR81-2, AFRRI, Bethesda, Md., 1981.

3.4B U.S. Army Facilities

3.4B.1 General Description

The U.S. Army Test and Evaluation Command operates two reactors: the Army Pulse Radiation Facility (APRF) at Aberdeen Proving Ground, Maryland, and the Fast Burst Reactor (FBR) at White Sands Missile Range, New Mexico. These reactors are very similar in design and are used to support Army and other Department of Defense studies in nuclear radiation effects.

3.4B.2 Process Description

Both Army reactors are bare, unreflected, unmoderated, and fueled with enriched uranium. These reactors are capable of self-limiting, super-prompt-critical pulse operations as well as steady-state operations at power levels up to 10 kW (EPA80). Operating information for the APRF and FBR for 1981 is summarized in Table 3.4B-1. The reactors are used primarily by DOD and defense contractors to study nuclear weapons effects on electronics and other DOD related equipment.

The White Sands FBR is the principal source of radioactive airborne emissions from Army reactors. At the FBR, concrete structures around the reactor reflect and thus lower the energy of neutrons streaming from the reactor. These low energy neutrons produce airborne radioactivity in the reactor building by neutron activation of stable argon-40 in air. Concrete structures at the APRF are farther from the reactor; hence, much less (essentially zero) argon-41 is produced at this facility (TRI79).

Table 3.4B-1. Number and modes of operations at Army Reactor Facilities, 1981 (Aa82, ARM81)

Type of operation	Number of operations	
	APRF	FBR
Pulse	211	252
Steady State	233	159
Unscheduled Terminations	-	8
Total	444	419

3.4B.3 Control Technology

Air exhausted from U.S. Army reactor facilities is passed through HEPA filters before release to the atmosphere.

3.4B.4 Radionuclide Emission Measurements

Radioactive emissions from Army reactors during 1976, 1978, and 1981 are listed in Table 3.4B-2. For the APRF, particulate releases are reported as gross beta concentrations only. All gaseous releases from the APRF were below the minimum detectable concentration of 3.0E-3 pCi/m^3.

Table 3.4B-2. Radionuclide emissions from Army Pulse Reactors

Radioactive material	Emissions (Ci/y)	
	APRF	FBR
Gross beta concentration:		
1976	2.8E-6	
1981	3.3E-5	
Argon-41:		
1976		11.7
1978		18.0
1981		13.3

Source: (De76, Aaa77, TRI79, Aab81, ARM81).

3.4B.5 Health Impact Assessment from Army Pulse Reactors

The estimated annual radiation doses resulting from radionuclide emissions from the White Sands FBR are listed in Table 3.4B-3. The distance to the nearest offsite individuals at the APRF and FBR are approximately 1.6 km and 2.0 km, respectively. The predominant exposure pathway is that of air immersion. These estimates are for a sparsely populated southwestern location with a regional population of 3.6E+4 (Reference Site E). The maximum individual is located 500 meters from the reactor.

Table 3.4B-4 lists the estimated individual lifetime risks and the number of fatal cancers to the regional population from these doses.

This assessment was made only for the White Sands FBR because nearly all measured radionuclide emissions from Army reactors originate at the FBR.

Table 3.4B-3. Radiation dose rates from radionuclide emissions from the White Sands Fast Burst Reactor

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Endosteal	2.6E-2	9.2E-2
Spleen	2.6E-2	9.4E-2
Red Marrow	2.4E-2	8.6E-2
Muscle	2.4E-2	8.7E-2
Pulmonary	2.3E-2	8.2E-2
Weighted Sum	2.3E-2	8.1E-2

Table 3.4B-4. Fatal cancer risks due to radionuclide emissions from the White Sands Fast Burst Reactor

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
FBR	5E-7	2E-5

3.4B.6 Existing Emission Standards and Air pollution Controls

Because Army pulse reactors are not licensed by NRC, they are not subject to radionuclide emission standards.

3.4B.7 Supplemental Control Technology

Emissions from Army pulse reactors consist mainly of argon-41, for which no demonstrated treatment technology exists. Reduction of argon-41 emissions are best controlled by work practice controls; e.g., reducing reactor operating time and reducing the amount of air subject to neutron irradiation by plugging air leaks into the reactor compartment.

REFERENCES

Aaa77 Aaserude R.A., Dickinson R. W., Dubyoski H. G., and Kazi A. H., APRF, Army Pulse Radiation Facility, Annual Operating Report, Aberdeen Proving Ground, Md., 1977

Aab82 Aaserude R.A., Dubyoski H. G., Harrell, D.R. and Kazi, A. H., Army Pulse Radiation Dividion Reactor, Annual Operating Report, Materiel Testing Directorate, Aberdeen Proving Ground, Md., 1982.

ARM81 Army Materiel Test and Evaluation Directorate, White Sands Missile Range Fast Burst Reactor, Annual Operating Report, Applied Sciences Division, White Sands Missile Range, N. M., 1981.

De76 De La Paz A. and Dressel R. W., White Sands Missile Range Fast Burst Reactor Facility, Annual Operating Report, Army Materiel Test and Evaluation Directorate, White Sands Missile Range, N.M., 1976.

TRI79 Teknekron Research, Inc., Information Base (Including Sources and Emission Rates) for the Evaluation and Control of Radioactive Materials to Ambient Air, Interim Report, Volume 1, EPA Contract No. 68-01-5142, July 1979.

3.4C U.S. Navy Facilities

3.4C.1 General Description

Airborne emissions of radionuclides from U.S. Navy facilities are due, almost entirely, to naval shipyards. Construction, overhaul, refueling, and maintenance of the 133 submarines and ships of the Navy's nuclear fleet are performed at nine naval shipyards at the following locations:

Mare Island Naval Shipyard, Vallejo, California
Electric Boat Division, General Dynamics, Groton, Connecticut
Pearl Harbor Naval Shipyard, Hawaii
Portsmouth Naval Shipyard, Kittery, Maine

Ingalls Shipbuilding Division, Pascagoula, Mississippi
U.S. Naval Station and Naval Shipyard, Charleston, S. C.
Newport News Shipbuilding and Drydock Co., Newport News, Va.
Norfolk Naval Shipyard, Portsmouth, Virginia
Puget Sound Naval Shipyard, Bremerton, Washington

3.4C.2 Process Description

Operations performed at naval shipyards include construction, startup testing, refueling, and maintenance of the pressurized water reactors that power the nuclear fleet. Radioactive wastes generated by these activities are processed and sealed at the shipyards and shipped to commercial waste disposal sites.

The primary sources of airborne radioactive emissions from naval shipyards are the support facilities that process and package radioactive waste materials for shipment to disposal sites. These facilities handle solid low-level radioactive wastes such as contaminated rags, paper, filters, ion exchange resins, and scrap materials.

During operation, shipboard nuclear reactors release small amounts of radioactivity (carbon-14) into the atmosphere; however, most of this is released at sea, beyond 12 miles from shore (Ri82).

3.4C.3 Control Technology

All air exhausted from radiological support facilities at naval shipyards is passed through HEPA filters and monitored during discharge. A comparison of airborne activity measurements in shipyards with radioactivity concentrations in ambient air indicates that air exhausted from these facilities actually contains less activity that the intake air (Ri82).

3.4C.4 Radionuclide Emission Measurements

Monitoring of effluents from nuclear naval shipyards began in 1963. To date, this monitoring has shown no concentration of airborne effluents in excess of naturally occurring background levels (TRI79).

Results of emission measurements taken at Puget Sound Naval Shipyard in 1974 are shown in Table 3.4C-1. These measurements showed that the tritium concentration was below the minimum detectable level of 1.0 pCi/l, and that the level of krypton-85 was within average background levels (EPA77).

Table 3.4C-1. Radionuclide emissions at Puget Sound Naval Shipyard, 1974

Source	Radionuclide	Emissions (pCi/l)
West of Radiological Support Building	Krypton-85	17.4 ± 10%
Radiological Support Building	Tritium	0.4 ± 50%
Radiological Support Building	Tritium	0.3 ± 66%

3.4C.5 Reference Facility

The typical nuclear shipyard processes, packages, and ships approximately 85 cubic meters of radioactive solid waste for disposal annually. The average activity of this material is approximately 6.3 curies. Waste packaging is performed in an enclosed facility, exhaust from which is passed through HEPA filters before release to the atmosphere. Air is exhausted from the radiological support facility at a height of about five meters.

Estimated radioactive emissions from the reference naval shipyard are listed in Table 3.4C-2. These are conservative, worst-case estimates used by the Navy in environmental pathways analysis, and are higher than any measurements made in the past five years at any shipyard (Ri82).

3.4C.6 Health Impact Assessment of the Reference Facility

The estimated annual radiation doses resulting from radionuclide emissions from the reference shipyard are listed in Table 3.4C-3. The distance to the nearest offsite individual is approximately one km. The predominant exposure pathway is that of ground shine. These estimates

Table 3.4C-2. Radionuclide emissions from the reference facility (Ri82)

Radionuclide	Emissions (Ci/y)
Argon-41	4.1E-1
Cobalt-60	1.0E-3
Tritium	1.0E-3
Carbon-14	1.0E-1
Krypton-83m	2.0E-2
Krypton-85m	2.4E-2
Krypton-85	1.0E-3
Krypton-87	5.0E-2
Krypton-88	2.0E-2
Xenon-131m	5.0E-3
Xenon-133m	1.0E-2
Xenon-133	2.1E-1
Xenon-135	2.5E-1

are for an urban site with a regional population of 2.5E+6 (Reference Site B). The maximum individual is located 500 meters from the radiological support facility.

Table 3.4C-4 presents estimates of the maximum individual lifetime risks and the number of fatal cancers to the regional population from these doses.

Table 3.4C-3. Radiation dose rates from radionuclide emissions from the reference facility

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Total body	1.6E-2	8.9E-2

Table 3.4C-4. Fatal cancer risks due to radionuclide emissions from the reference facility

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Nuclear naval shipyard	3E-7	3E-5

3.4C.7 Total Health Impact of U.S. Nuclear Naval Shipyards

The estimated total number of fatal cancers caused by all naval shipyards is about 3E-4 per year. This estimate was derived from the ratio of the capacity of the reference shipyard to the capacity of all nuclear naval shipyards.

3.4C.8 Existing Emission Standards and Air Pollution Controls

There is no demonstrated treatment technology for controlling emissions of krypton-85 or other radioactive noble gases from radiological support facilities.

Tritium emissions could be controlled by using a catalytic recombiner; however, this would be impractical considering the extremely low levels of tritium emitted from radiological support facilities.

REFERENCES

EPA77	Environmental Protection Agency, Radiological Survey of Puget Sound Naval Shipyard, Bremerton, Washington, and Environs, EPA-520/5-77-001, Office of Radiation Programs, EPA, Washington, D.C., 1977.
Ri82	Rice, P. D., Sjoblom G. L., Steele J. M. and Harvey B. F., Environmental Monitoring and Disposal of Radioactive Wastes from U.S. Naval Nuclear-Powered Ships and Their Support Facilities, Report NT-82-1, Naval Nuclear Propulsion Program, Department of the Navy, Washington, D.C., 1982.
TRI79	Teknekron Research, Inc., Information Base (Including Sources and Emission Rates) for the Evaluation and Control of Radioactive Materials to Ambient Air, Interim Report, Volume 1, EPA Contract No. 68-01-5142, July 1979.

3.5 Radiation Source Manufacturers

3.5.1 General Description

The term "radiation source" refers to radioactive material which is enclosed in a sealed container or other nondispersible matrix. Radiation sources are used in a wide variety of industrial and consumer products including: (1) radioisotope gauges, which measure the thickness of industrial products, (2) static eliminators, which are used to reduce static electricity in industrial machines, (3) nondestructive testing equipment, (4) self-illuminating signs and watch dials, and (5) smoke detectors (EPA79).

3.5.2 Process Description

Radiation source manufacturers process bulk quantities of radioactive materials received from radionuclide production facilities such as accelerators or reactors. During the manufacturing process, the radioactive materials are handled with remote manipulators and custom-made enclosures, such as glove boxes.

The manufacturers are licensed by NRC to have inventories of radioactive materials in quantities ranging from ten Ci to as high as 100,000 Ci.

3.5.3 Emission Control Systems

Radiation source manufacturers use many different radionuclides in their operations. In addition to conventional filtration systems for removal of particulate matter, manufacturers may use other kinds of treatment systems which are applicable to their particular emissions. For example, tritium emissions can be reduced by use of desiccant type scrubber columns which remove tritiated water; radioiodine releases can be controlled with charcoal filters; facilities with emissions of krypton or xenon can use chilled charcoal traps to delay the release of these gases until radioactive decay has reduced their activity.

3.5.4 Radionuclide Emissions

Each radiation source manufacturer handles a unique combination of radionuclides; therefore, each site has unique emission characteristics. Table 3.5-1 shows radionuclide emission data on eighteen manufacturing sites; these data were taken from reports submitted to NRC.

3.5.5 Reference Facility

For this analysis, a reference facility was created by summing all of the radionuclides emitted by the eighteen sites listed in Table 3.5-1. Other parameters used in the analysis were assumed to be those of an industrial zone in a suburban area adjacent to a major city in the midwestern United States. Table 3.5-2 describes the parameters of the reference facility.

3.5.6 Health Impact Assessment of Reference Facility

The estimated annual radiation doses from the reference facility for individuals and population groups are shown in Table 3.5-3. Individual fatal cancer risks and committed population fatal cancers are presented in Table 3.5-4. The lifetime fatal cancer risk to the individuals at highest risk is estimated to be 5E-6. The individual at highest risk is located 500 meters north of the source.

The estimated number of potential fatal cancers to the population living in the region around the reference facility is estimated to be 2E-3 per year of facility operation.

Because of the way in which the reference facility was artifically created, the maximum individual risk estimated for the reference facility is much higher than the actual maximum individual risk associated with any individual site. The population risk estimated for the reference facility is equal to the total population risk for the eighteen sites listed in Table 3.5-1.

3.5.7 Total Health Impact

The estimated number of fatal cancers caused by all radiation source manufacturers is 2E-3 per year of operation, the same number as the reference facility, because of the way in which the reference facility was created.

3.5.8 Existing Emission Standards and Air Pollution Controls

Radiation source manufacturers licensed by NRC are subject to the requirements of 10 CFR 20.106, which places limits on air emissions to unrestricted areas. The particular controls used by a licensee to meet these requirements will depend on the particular radionuclide(s) involved and other factors unique to that licensee.

Table 3.5-1. Radionuclide emisssions from radiation source manufacturers (Co83)

Site	Radionuclide	Emissions (Ci/y)
A	none	0.0
B	Kr-85	1.3
C	H-3	3E-1
D	Kr-85	5E-1
E	Th-232	1.4E-1
F	Kr-85	1E-3
G	H-3	5.4E+1
	Kr-85	5E+1
H	H-3	5E+1
I	none	0.0
J	I-125	2E-2
	Kr-85	2.5
	Cs-137	2E-3
K	H-3	2.14E+2
	C-14	4.3
	S-35	1.2E-1
L	H-3	2.5E-1
M	H-3	7.4E+2
N	H-3	3E-1
O	H-3	3E-2
P	Kr-85	2E-1
Q	Kr-85	2E-3
	Xe-133	2E-2
R	Kr-85	7.3

Table 3.4-2. Reference radiation source manufacturer

Parameter	Value
Fraction of radionuclides released:	
Tritium	1060
Krypton-85	61.8
Carbon-14	4.3
Stack height	10 meters

Table 3.5-3. Radiation dose rates from radionuclide emissions from the reference radiation source manufacturer

Organ	Maximum individual (mrem/y)	Regional popultion (person-rem/y)
Weighted sum	0.22	8.4

Table 3.5-4. Fatal cancer risks due to radionuclide emissions from the reference radiation source manufacturer

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Reference facility	5E-6	2E-3

REFERENCES

Co83 Corbit C. D., et. al, Background Information on Sources of Low-level Radionuclide Emissions to Air, PNL-4670, (Draft report), Pacific Northwest Laboratory, Richland, Washington, March 1983.

EPA79 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, Preliminary Report, EPA 520/7-79-006, August 1979.

Chapter 4: COAL-FIRED UTILITY AND INDUSTRIAL BOILERS

4.0 Introduction

Large coal-fired boilers are used to generate electricity for public and industrial use, as well as to provide process steam, process hot water, and space heat. For the purposes of this report, boilers used in the utility industry are designated utility boilers and those used primarily to generate process steam/hot water are designated industrial boilers.

From 1974 to 1977, about 18 percent of the energy needs in the United States were met by burning coal; 60 percent to generate electricity, and about 32 percent for industrial uses. More than 600 million tons are burned each year in utility and industrial boilers (EPA 81).

Coal contains trace quantities of naturally-occurring radionuclides. Table 4.0-1 lists typical concentrations of uranium and thorium in U.S. coals. Uranium-238 and thorium-232 are the radionuclides in coal with the longest half-lives. Other radionuclides in coal are decay products of either uranium-238 or thorium-232 and are in secular equilibrium with them. Tables 4.0-2 and 4.0-3 show the major decay products of uranium-238 and thorium-232, respectively.

As coal is burned, the minerals in the coal melt and then condense into a glass-like ash. A portion of ash settles to the bottom (bottom ash) of the boiler and a portion enters the flue gas stream (fly ash). Both the bottom ash and fly ash contain the radionuclides orginally present in the coal, but more tends to combine with the fly ash. The fraction of fly ash that is not trapped by emission control equipment and that is released into the environment carries with it radionuclides; the quantity released depends upon the radionuclide content of the coal, furnace design, and efficiency of the particulate matter control system.

Radionuclides that are contained in fly ash exhausted to the environment may expose people in several ways: they may be inhaled; they may settle onto the ground and expose people nearby; and they may settle onto crops or be taken up through the roots of crops and then be eaten. Humans exposed to radiation by any of these means have an increased risk of cancer and other health effects.

Table 4.0-1. Typical uranium and thorium concentrations in coal

Region/Coal	Uranium		Thorium	
	Range (ppm)	Mean (ppm)	Range (ppm)	Mean (ppm)
Pennsylvania				
Anthracite	0.3 - 25	1.2	2.8 - 14	4.7
Appalachian				
Bituminous	0.2 - 11	1.0	2 - 48	2.8
NR	0.4 - 39	1.3	1.8 - 94	
Bituminous	---	1.1	-	2.0
Bituminous	0.1 - 19	1.2	-	3.1
Illinois Basin	0.3 - 5	1.3	0.7 - 5	1.9
Bituminous	0.2 - 43	1.4	3 - 79	1.6
Bituminous	0.2 - 59	1.7	0.0 - 79	3
Northern Great Plains				
Bituminous-Subbituminous	0.2 - 3	0.7	2 - 8	2.4
Subbituminous	0.1 - 16	1.0	0.1 - 42	3.2
Lignite	0.2 - 13	1.2	0.3 - 14	
Western				
NR	0.3 - 2.5	1.0	0.6 - 6	2.3
Rocky Mountain				
Bituminous-Subbituminous	0.2 - 24	1.0	3 - 35	2.0
Subbitumnious	0.1 - 76	1.9	0.1 - 54	4.4
Bituminous	0.1 - 42	1.4	0.2 - 18	3.0
Average for all coals		1.3		3.2

Source: TRI81.

Note: 1 ppm uranium-238 is equivalent to 0.34 pCi/g of coal.
1 ppm thorium-232 is equivalent to 0.11 pCi/g of coal.
NR Not reported.

Table 4.0-2. Major decay products of uranium-238

Radionuclide	Half-life	Principal radiation (Mev)		
		Alpha	Beta	Gamma
Uranium-238	4.5×10^9 y	4.20		
Thorium-234	24 d		0.044	0.008
Protactinium-234	1.2 m		0.82	0.011
Uranium-234	2.4×10^5 y	4.76		
Thorium-230	7.7×10^4 y	4.66		
Radium-226	1.6×10^3 y	4.77		0.006
Radon-222	3.8 d	5.49		
Polonium-218	3.1 m	6.00		
Lead-214	27 m		0.22	0.23
Bismuth-214	20 m		0.63	2.03
Polonium-214	1.6×10^{-4} s	7.69		
Lead-210	22 y		0.007	0.002
Bismuth-210	5.0 d		39	
Polonium-210	138 d	5.31		

Table 4.0-3. Major decay products of thorium-232

Radionuclide	Half-life	Principal radiation (Mev)		
		Alpha	Beta	Gamma
Thorium-232	1.4×10^{10} y	4.00		
Radium-228	5.8 y		0.010	
Actinium-228	6.1 h		0.376	0.915
Thorium-228	1.9 y	5.40		0.002
Radium-224	3.7 d	5.67		0.009
Radon-220	55 s	6.29		
Polonium-216	0.15 s	6.78		
Lead-212	10 h		0.100	0.117
Bismuth-212	60 m		0.717	0.281
Thallium-208	3.1 m		0.561	2.37
Polonium-212	3.1×10^{-7} s	8.78		

y = years d = days h = hours m = minutes s = seconds

4.1 Utility Boilers

4.1.1 General Description

At the end of 1979, the total capacity of U.S. electric utility generating units amounted to 593 gigawatts (GW) (TRI81). Table 4.1-1 lists the capacity of the utility industry for 1979 and projections for 1985. Coal-fired steam electic power units accounted for 38 percent of total capacity and 49 percent of total energy generation in 1979. Coal-fired steam electric plants will account for 40 percent of total generating capacity and for 49 percent of total power generation by 1985.

Power plants are designed and operated to serve three load classes: (a) base-load plants, which operate near full capacity most of the time (or are dispatched to operate in the most efficient region of the heat rate curve); (b) intermediate-load (or cycling) plants, which operate at varying levels of capacity each day (about 40 percent utilization on an average annual basis); and (c) peaking plants, which operate only a few hours per day (about 700-800 hours per year). Fossil-fueled steam electric plants now dominate base-load and intermediate-load service.

The average national capacity factor dropped from 55 percent in 1970 to 47 percent in 1978; the average base-load capacity factor, from 68 percent in 1970 to 64 percent in 1978. The average capacity factor for cycling units remained almost constant over this period (TRI81).

Capacity and Age of Coal-Fired Steam Units

There were 1,224 coal-fired units with a total generating capacity of 225 GW on line in 1979 (the base year). The distribution of these units by capacity and age is shown in Table 4.1-2. About 50 percent of coal-fired capacity is less than 10 years old. Most of the units with capacities of 26 to 100 MW are between 25 and 29 years old, while those with capacities of 101 to 300 MW are between 20 and 24 years old. Units larger than 300 MW are 5 to 9 years old. About 21 percent of the coal-fired units account for 50 percent of total generating capacity.

By 1985 there will be 1,360 coal-fired units on line with a capacity of 307 GW, an increase over the base year of approximately 36 percent (TRI81). In 1985, capacity of units less than 5 years old will account for 22 percent of the total projected capacity and for about 10 percent of the total number of units.

The retirement rates for fossil units of a given capacity and size will significantly affect system composition by 1985. Seventy-nine coal units are scheduled for retirement by 1985. No retirements are scheduled for units greater than 300 MW in capacity.

Table 4.1-1. U.S. electric utility generating capacity (Gigawatts)

Generating technology	1979 (GW)	1979 (% of total)	1985 (GW)	1985 (% of total)
Coal-fired steam electric	225.1	(38.0)	306.0	(40.0)
Oil-fired steam electric	101.4	(17.1)	112.5	(14.7)
Gas-fired steam electric	59.9	(10.1)	39.5	(5.2)
Combined-cycle plants	2.5	(.4)	5.3	(.7)
Combustion gas-turbine, internal combustion	76.9	(13.0)	102.4	(13.4)
Nuclear	51.1	(8.6)	112.6	(14.7)
Hydroelectric	73.3	(12.4)	77.9	(10.1)
Geothermal	.9	(.2)	1.9	(.2)
Others	2.0	(.3)	7.9	(1.0)
Total	593.1	(100.1)*	766.0	(100.0)

Source: (TRI81).
*Percentages do not add to 100.0 due to rounding.

Coal consumption by the electric utilities is expected to increase from 438 million metric tons in 1979 to 633 million metric tons in 1985 (TRI81).

4.1.2 Process Description

In the typical power plant, a mixture of finely ground coal and air is blown into a combustion chamber at the base of the boiler and ignited as it passes through a burner. In the upper portion of the boiler (above the combustion zone), boiler feedwater is simultaneously pumped through a series of metal tube banks. The heat contained in combustion gases is transferred to the feedwater which ultimately leaves the boiler as saturated steam. This high-temperature, high-pressure steam (540° C at 2.46 kgs/cm^2) is used to drive a turbine that, in turn, drives an electric generator. Vapor leaving the turbine is fed to a cooling system that extracts residual heat and recycles condensate water back to the boiler.

Coal combustion produces an ash that is either retained within the boiler (bottom ash) or carried out of the boiler with combustion

Table 4.1-2. Distribution of U.S. coal-fired units by age and capacity, 1979

Age	Capacity of coal-fired units									
	0.03-0.1 GW		0.1-0.3 GW		0.3-0.6 GW		Greater than 0.6 GW		Totals[a]	
	(Units)	(GW)	(Units)	(GW)	(Units)	(GW)	(Units)	(GW)	(Units)	(GW)
0-4	6	0.5	21	4.6	54	24.8	30	22.4	120	52.4
5-9	9	0.5	22	4.2	44	20.2	42	33.8	139	58.9
10-14	19	1.3	42	8.5	40	18.0	12	8.7	132	36.8
15-19	26	1.6	73	13.8	18	7.1	2	1.3	140	24.2
20-24	36	2.3	130	22.3	4	1.3	0	0	204	26.3
25-29	104	7.1	83	11.3	0	0	0	0	255	19.3
30-34	60	3.4	4	0.5	0	0	0	0	121	4.5
35-39	32	1.8	0	0	0	0	0	0	58	2.0
40-44	3	0.1	0	0	0	0	0	0	24	0.3
45-49	2	0.1	0	0	0	0	0	0	7	0.1
50-54	2	0.1	0	0	0	0	0	0	16	0.2
55-59	0	0	0	0	0	0	0	0	6	0.1
60	0	0	0	0	0	0	0	0	2	0.01
Total	299	18.8	375	65.2	160	71.4	86	66.2	1224	225.1

Source: (TRI81).

[a] Totals include an additional 304 units having a total capacity of 3.5 GW in the 0-0.03 GW range.

gases (fly ash). A portion of the fly ash is removed from the flue gas before it is released to the atmosphere by a particulate control system.

Fly ash, bottom ash, slag, scrubber sludges, are removed from the boiler and accumulate in solid waste piles adjacent to the plant. These waste piles may range in area from 80 to 100 hectares for a single 550 MW unit. In 1977 about 50 M metric tons of ash were generated by coal-fired electric generating plants in the United States. Some of the ash is stored near or on the station site; some is returned to a coal mine for disposal; and some can be used.

Furnace Design

The distribution of particulates between bottom ash and fly ash depends on the firing method, the ash fusion temperature of the coal, and the type of boiler bottom (wet or dry).

Fuel-firing equipment (Table 4.1-3) can be divided into three general categories: stoker furnace (dry bottom), composed of spreader or non-spreader types; cyclone furnace (wet bottom); and pulverized-coal furnace (dry or wet bottom) (TRI81).

Table 4.1-3. Classification of coal-fired units by firing method and type of boiler bottom, 1976

	Number of units	Generating capacity (MW)	Percent of total
Stoker (all dry bottom)	165	2,015	(1.0)
Cyclone (all wet bottom)	94	24,449	(12.0)
Pulverized (wet bottom)	135	16,440	(8.0)
Pulverized (dry bottom)	837	161,092	(79.0)
Total	1231	203,996	

Source: (TRI81).

Note: Total number of units and generating capacity in Table 4.1-3 are slightly different from previously-mentioned figures because of unit retirements, derating, etc.

Stoker-Fired Furnaces. Stoker furnaces are usually small, old boilers ranging in capacity from 7.3 to 73 MW (thermal). Of the boilers designed for coal and sold from 1965 to 1973, none exceeded 143 MW(t); 63 percent were stoker-fired; 41 percent, spreader stoker; 9 percent, underfeed stoker; and 13 percent, overfeed stoker. Stokers require about 3.3 kg of coal per kilowatt-hour and are less efficient than units handling pulverized coal. Stoker-fired units produce relatively coarse fly ash. Sixty-five percent of the total ash in spreader stokers is fly ash.

Cyclone Furnaces. Crushed coal is burned in a high-temperature combustion chamber called a cyclone. The high temperatures in the furnace lead to the formation of a molten slag which drains continuously into a quenching tank. Roughly 80 percent of the ash is retained as bottom ash. Only 9 percent of the coal-fired utility boiler capacity in 1974 was of the cyclone type, and no boilers of this kind have been ordered by utilities in the past seven years (TRI81).

Pulverized-coal Furnaces. Coal is pulverized to a fine powder (approximately 200 mesh) and injected into the combustion zone in an intimate mixture with air. Pulverized-coal furnaces are designed to remove bottom ash as either a solid (dry-bottom boiler), or as a molten slag (wet-bottom boiler).

The dry-bottom, pulverized-coal-fired boiler, in which the furnace temperature is kept low enough to prevent the ash from becoming molten, is now the most prevalent type of coal-burning unit in the utility sector. About 80 to 85 percent of the ash produced in the dry-bottom, pulverized-coal-fired boiler is fly ash. The remainder of the ash falls to the bottom of the furnace, where it is either transported dry or cooled with water and removed from the boiler as slurry to an ash-settling pond.

Mode of Operation

The new units have historically been used for base load generation; cycling capacity has been obtained by downgrading the older, less efficient, base load equipment as more replacement capacity comes on line.

In 1979, the average capacity factor(1) for coal-fired units operating in the base load mode was 65 percent; for units operating in a cycling mode, 42 percent (TRI81). The availability(2) of a coal-fired unit generally declines with increasing generating capacity. Generating units with capacities of less than 400 MW have average availabilities of more than 85 percent; those with capacities of more than 500 MW, only 74 to 76 percent (TRI81). The operating mode affects the heat rate of the plant; for example, changing the capacity factor from 42 to 70 percent changed the heat rate from 12.3 to 9.2 MJ/kWh.

4.1.3 Control Technology

Four types of conventional control devices are commonly used for particulate control in utility boilers: electrostatic precipitators (ESPs), mechanical collectors, wet scrubbers, and fabric filters. Comprehensive evaluations of each control device have been given in several publications (TRI81).

Selection of the particulate control device for a given unit is affected by many parameters, including boiler capacity and type, inlet loading, fly ash characteristics, inlet particle size distribution, applicable regulations, and characteristics of the control device itself. The location of particulate control devices with respect to SO_2 scrubber systems in a plant depends on the type of scrubbers (wet or dry) installed; these devices are located upstream of a wet scrubber system or downstream of a spray dryer system.

---

(1) Capacity factor equals the ratio of energy actually produced in a given period to the energy that would have been produced in the same period had the unit been operated continuously at its rated power.

(2) Availability refers to the fraction of a year during which a unit is capable of providing electricity to the utility grid at its rated power after planned and forced outages have been accounted for.

ESPs with collection efficiencies of more than 99.8 percent have historically been the control device of choice for utility boilers. However, as a result of the growing use of low-sulfur western coals, wet scrubbers and fabric filters have increasingly been chosen.

Table 4.1-4 shows the distribution of control equipment in use in 1976 on coal-fired steam electric boilers (TRI81).

4.1.4 Radionuclide Emissions

The emission of radionuclides in the fly ash generated during combustion depends on the type of coal used; that is, its mineral content and the concentrations of uranium, thorium, and their decay products. Other factors influencing radionucide emissions include furnace design, capacity, capacity factor, heat rate, ash partitioning, enrichment factors, and emission control efficiency (Table 4.1-5). The distribution of ash between the bottom and fly ash depends on the firing method, coal, and furnace (dry bottom or wet bottom). For pulverized-coal, dry bottom units, 80-85 percent of the ash is fly ash.

Recent measurements have shown that trace elements, such as uranium, lead, and polonium, are partitioned unequally between bottom ash and fly ash (Be78, Wa82). Although the concentration mechanism is not fully understood, one explanation is that certain elements are preferentially concentrated on the particle surfaces, resulting in their depletion in the bottom ash and their enrichment in the fly ash (Sm80). The highest concentration of the trace elements in fly ash is found in particulates in the 0.5 to 10.0 micrometer diameter range, the size range that can be inhaled and deposited in the lung. These fine particles are less efficiently removed by particulate control devices than larger particles. Based on measured data, typical enrichment factors are: 2 for uranium, 1.5 for radium, 5 for lead and polonium, and 1 for all other radionuclides (EPA81).

Coal storage and waste piles at utility boiler sites are also potential sources of radon-222. Analyses of fugitive emission data from these piles indicate, however, that the radon-222 "exhalation rate" is less than that for soil, as reported by Beck (Be81).

Measured Radionuclide Emissions

EPA has measured radionuclide emissions at nine utility boilers. Summaries of emissions data from these studies are presented in Tables 4.1-6 and 4.1-7.

Table 4.1-4. Particulate emission control equipment by type of boiler, 1976

Control equipment	Stoker		Pulverized cyclone		Pulverized wet bottom	
	Capacity (GW)	Units	Capacity (GW)	Units	Capacity (GW)	Units
No control	0.7	76	3.9	18	4.5	66
Mechanical[a]	0.8	63	1.2	7	0.5	11
Wet scrubbers	–	–	–	–	–	–
Fabric filters	0.1	2	–	–	–	–
ESP	–	–	19.0	62	9.5	44
Combination[b]	0.4	24	0.4	7	2.0	14

Control equipment	Dry bottom		Total	
	Capacity (GW)	Units	Capacity (GW)	Units
No control	26.8	266	35.9	426
Mechanical[a]	2.4	50	4.9	131
Wet scrubbers	1.9	7	1.9	7
Fabric filters	0.8	3	0.9	5
ESP	110.1	374	138.5	480
Combination[b]	19.2	137	22.0	182

[a] Mechanical devices include cyclones and gravitational chambers.
[b] Combination refers to mechanical-electrostatic precipitators.
Source: (TRI81).

Table 4.1-5. Parameters affecting radionuclide emissions from coal-fired units

Parameter	Effect
Coal properties (heating value, mineral matter, moisture and sulfur content)	Radionuclide content of ash depends directly on the amounts of uranium, thorium, and their daughters contained in the coal, and the percentage of mineral matter in the coal.
Heat rate	Total particulate release is directly related to coal consumption, which in turn depends on heat rate.
Capacity	Total particulate emission is directly related to unit size.
Mode of operation (capacity factor)	Mode of operation affects capacity factor and heat rate, which in turn influences total particulate emissions.
Ash partitioning	Partitioning of ash between bottom and fly ash directly affects particulate emission rate.
Enrichment of radionuclides in fly ash	The enrichment of certain radionuclides in the fly ash relative to the bottom ash directly affects the radionuclide emission rate.
Type of control device	Rate of particulate release depends on the efficiency of control devices.

Estimated Radionuclide Emissions Based on Particulate Emissions

An estimate of the radioactivity released by coal-fired utility boilers may be made by multiplying the particulate release rate (g/y) by the average concentration of radionuclides in fly ash (pCi/g). The concentration of radionuclides in fly ash depends on the concentrations of uranium-238 and thorium-232 and their decay products in the coal, the ash content of the coal, the partitioning between fly ash and bottom ash, and the enrichment factors for the radionuclides in the fly ash. Using typical values of 1.3 ppm uranium-238 and 3.2 ppm thorium-232 in coal (see table 4.0-1), 7.6 percent ash in coal (TRI81), a partitioning factor of 0.8 for fly ash (TRI81), enrichment factors of 2 for uranium and 1 for thorium, and the specific activities of uranium and thorium, the calculated values for uranium and thorium in fly ash are 9 pCi/g and 4 pCi/g, respectively. Values for the other radionuclides in the uranium and thorium series may be derived by applying enrichment factors of 1.5 for radium, 5 for lead and polonium, and 1 for all other radionuclides.

Particulate emissions from coal-fired boilers have been listed by EPA's National Emissions Data System (NEDS) (EPA80a). Data from this system were used to select units releasing the largest amounts of particulates into the atmosphere. The estimated uranium and thorium emission rates (assuming 9 pCi of uranium-238 and 4 pCi of thorium-232 per gram of fly ash) for these units are listed in Table 4.1-8.

Table 4.1-6. Radionuclide emission rates (mCi/y) measured at selected coal-fired steam electric generating stations

Radionuclide	Sampling location[a]			
	M-1	M-2	M-3	M-4
Uranium-238	24	5.7	0.76	0.10
Uranium-234	24	7.2	0.81	0.10
Thorium-230	1.5	4.1	0.29	0.08
Radium-226	5.3	4.1	0.21	0.02
Lead-210	28	15	1.4	0.18
Polonium-210	68	14	1.1	0.16
Thorium-232	0.81	1.5	0.02	0.05
Thorium-228	0.72	1.7	0.30	0.05

Source: EPA80b

[a] Sampling locations:

M-1 West North Central Station (874 MW).
M-2 East North Central Station (450 MW).
M-3 South Atlantic Station (125 MW).
M-4 Mountain Station (12.5 MW).

The particulate emission rate for all the coal-fired utility boilers in the United States has been estimated by NEDS to be 0.9 million metric tons per year. Assuming 9 pCi U/g fly ash, this results in an annual emission rate of about 8 curies of uranium-238 for the industry.

4.1.5 Reference Facility

The annual emissions of radionuclides from coal-fired utility boilers cover a very large range because of the large range of coal properties, boiler parameters, and control efficiencies. In order to assess the health impact of these facilities, a reference coal-fired utility boiler was defined. The uranium-238 emission rate for the reference facility of 100 mCi/yr was selected on the basis of EPA's judgment as representative of the upper range of potential emissions (see Table 4.1-8). Such emissions could be obtained from large well-controlled boilers burning coal with relatively high uranium content, or from large boilers with fewer controls burning coal of average or less than average uranium content.

The source term for the reference facility is defined in Table 4.1-9. The annual emissions for thorium, radium, lead, and polonium reflect the fly ash enrichment factors noted previously. The reference facility is assumed to have a stack height of 185 meters and a plume rise of 50 meters, typical of large utility boilers.

Table 4.1-7. Summary of radionuclide emission rates (mCi/y) measured at five coal-fired steam electric generating units

Radionuclide	Sampling location(a)				
	M-1	M-33	M-15	M-34	M-99
Uranium-238	100	11	0.2	2	0.03
Thorium-230	12	8.8	0.2	0.5	0.04
Radium-226	45	11	0.3	4	0.1
Polonium-210	1000	30	< 0.6	3	< 3.0
Lead-210	220	20	(b)	3	(b)
Thorium-232	1.3	6.5	0.04	0.5	0.01

Source: (Re82).

(a)Sampling locations and particulate control devices used at each of the units are:

M-1 West North Central unit (874 MW gross); wet limestone scrubber.
M-33 South Central unit (593 MW gross); cold side ESP.
M-15 North Central unit (56 MW gross); mechanical collector followed by a wet venturi scrubber.
M-34 South Central unit (800 MW gross); cold side ESP and baghouse followed by a wet limestone scrubber.
M-99 North Central unit (75 MW gross); mechanical collector followed by an ESP.

(b)No lead-210 analysis was made on samples collected at these units.

4.1.6 Health Impact Assessment of the Reference Utility Boiler

Because utility boilers may be located near large cites or at remote sites, the health impact of the reference facility was determined at four sites classified as urban, suburban, rural, and remote (see Table 4.1-10).

Table 4.1-8. Estimated uranium-238 emission rates from selected utility boilers emitting the largest amounts of particulate matter

Unit	Control device	Percent efficiency	Particulate emission rate (t/y)	Estimated U-238 emission rate (mCi/y)	Estimated Th-232 emission rate (mCi/y)
A	None	0	23,900	210	95
B	Mechanical Collector	50	9,300	80	35
C	Mechanical Collector	78	12,300	100	50
D	Mechanical Collector	90	6,600	60	25
E	ESP	75	21,100	190	80
F	ESP	85	23,900	210	95
G	ESP	91	18,100	160	70

Source: National Emission Data System (EPA80a).

Table 4.1-9. Radionuclide emissions from the reference facility

Radionuclide	Emissions (Ci/y)
Uranium series	
Uranium-238	1.0E-1
Uranium-234	1.0E-1
Thorium-230	5.0E-2
Radium-226	7.5E-2
Radon-222	9.6E-1
Lead-210	2.5E-1
Polonium-210	2.5E-1
Thorium series	
Thorium-232	4.3E-2
Radium-228	6.5E-2
Actinium-228	4.3E-2
Thorium-228	4.3E-2
Radium-224	6.5E-2
Radon-220	8.3E-1
Lead-212	2.2E-1
Bismuth-212	4.3E-2
Thallium-208	4.3E-2

Table 4.1-10. Population distribution of the reference facility

Site	Population(a)
Urban	1.72E+7
Suburban	2.49E+6
Rural	5.89E+5
Remote	1.19E+4

(a)Number of people located within a radius of 80 km.

The estimated annual radiation doses from radionuclide emissions from the reference boiler are presented in Table 4.1-11.

Table 4.1-12 presents estimates of the maximum individual lifetime risks and the number of fatal cancers to the regional population resulting from particulate doses at each of the generic sites for the reference unit. The urban site is a conservative selection, and estimates for this site represent an upper limit of the potential health impact to a regional population.

The highest lifetime risk to the maximum individual is estimated to be 4E-5 at the rural location due to external radiation from radionuclides deposited on the ground surface. The highest number of potential fatal cancers per year of operation is estimated to be 2E-1 at the urban location mainly from inhalation of radioactive fly ash particles.

4.1.7 Health Impact Assessment of Specific Utility Boilers

EPA surveyed emissions from five utility boilers located in areas similar to the generic rural site. The emission rates for these boilers are listed in Table 4.1-7. Using the generic rural site data and the actual emission rates measured by EPA, estimated annual radiation doses were calculated (Tables 4.1-13 and 4.1-14).

Table 4.1-15 presents estimates of the maximum individual lifetime risks and the number of fatal cancers to the regional population. The risk values for the M-1 unit are within a factor of three of the risk values for the reference boiler at the rural site which has similar emission rates.

Table 4.1-11. Radiation dose rates from radionuclide emissions from the reference utility boiler

Organ	Urban site		Suburban site	
	Maximum individual (mrem/y)	Regional population (person-rem/y)	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	9.9E-1	4.2E+3	1.3	3.9E+2
Red marrow	1.0E-1	3.4E+2	2.1E-1	3.4E+1
Kidney	1.0E-1	2.0E+2	2.3E-1	1.9E+1
Bone	1.2	4.8E+3	1.8	4.4E+2
Liver	5.0E-2	9.9E+1	1.4E-1	1.1E+1

Table 4.1-11. Radiation dose rates from radionuclide emissions from the reference utility boiler--continued

Organ	Rural site		Remote site	
	Maximum individual (mrem/y)	Regional population (person-rem/y)	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	1.7	1.1E+2	1.2	1.1
Red marrow	2.1	1.7E+1	1.4E-1	1.0E-1
Kidney	2.4	1.3E+1	9.0E-2	4.0E-2
Bone	4.7	1.3E+2	1.4	1.2
Liver	1.9	1.0E+1	6.0E-2	3.0E-2

Table 4.1-12. Fatal cancer risks from the reference facility

Site	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Urban	4E-6	2E-1
Suburban	6E-6	2E-2
Rural	4E-5	7E-3
Remote	5E-6	5E-5

Table 4.1-13. Radiation dose rates to the maximum individual from radionuclide emissions from five utility boilers

Organ	Maximum individual (mrem/y)				
	M-1	M-33	M-15	M-34	M-99
Lung	5.4E-1	4.3E-1	2.5E-2	5.5E-2	7.5E-3
Red marrow	8.7E-1	3.3E-1	7.0E-3	6.6E-2	3.2E-3
Kidney	3.8	3.3E-1	6.3E-3	5.8E-2	1.3E-2
Bone	2.0	8.9E-1	3.7E-2	1.4E-1	1.4E-2
Liver	1.2	2.7E-1	4.9E-3	5.4E-2	5.9E-3

Table 4.1-14. Radiation dose rates to the regional population from radionuclide emissions from five utility boilers

Organ	Regional population (person-rem/y)				
	M-1	M-33	M-15	M-34	M-99
Lung	7.0E+1	2.1E+1	7.1E-1	2.5	2.7E-1
Red marrow	5.2	3.2	7.9E-2	4.0E-1	2.6E-2
Kidney	2.2E+1	1.9	4.1E-2	3.0E-1	9.4E-2
Bone	2.3E+1	3.0E+1	8.5E-1	1.9	2.0E-1
Liver	6.6	1.4	2.9E-2	2.7	3.9E-2

Table 4.1-15. Fatal cancer risks from radionuclide emissions from five utility boilers

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
M-1	1E-5	4E-3
M-33	6E-6	1E-3
M-15	2E-7	4E-5
M-34	1E-6	2E-4
M-99	6E-8	2E-5

4.1.8 Total Health Impact of Utility Boilers

An estimate of the potential health impact of utility boilers presently in operation may be made by assuming that the health effects due to emissions from the reference boiler are proportional to the health effects due to emissions from the whole industry.

About eight curies of uranium-238 per year are emitted by the whole industry. Most of the U.S. generating capacity from coal-fired utility boilers is located in areas that would be classified as either suburban or rural. The estimates of health risks for the reference facility at these locations are about 1E-1 to 2E-1 potential fatal cancers per year per curie of uranium-238 released to the atmosphere. Thus, the health impact from the industry is about eight times this or about one to two potential fatal cancers per year.

4.1.9 Existing Emission Standards and Air Pollution Controls

There are no radionuclide emission standards for utility boilers. Particulate emission rates are regulated by EPA and the States, however. EPA administers New Source Performance Standards (NSPS) that apply to all utility boilers on which construction began after August 17, 1971, and before September 19, 1978, that have a firing capacity greater than 73 MW(t) or 25 MW(e). Under these standards, particulate emissions are limited to 43 ng/J. The 1979 revised New Source Performance Standards (RNSPS), which apply to all 73 MW(t) or 25 MW(e) electric utility steam generating units on which construction began after 19 September 1978, require that particulate emissions be limited to 13 ng/J (TRI81).

States regulate particulate emissions by State Implementation Plans (SIPs). These must ensure that emission limitations and reductions at new power plants are at least as stringent as those stipulated in the NSPS and RNSPS. The SIPs must also include emission limits for existing facilities (SIPs relate to National Ambient Air Quality Standards--
NAAQS) under 40 CFR 50; EPA rules for SIPs are in 40 CFR 60, Subpart B).

All plants that were operating or under construction before August 17, 1978, must be assigned emission limits by the SIP to ensure attainment of air quality standards.

In most States, the SIP emission limits for pre-NSPS plants are considerably less stringent than the NSPS limits. A survey of current SIP limits shows that values of 43 and 86 ng/J are typical for the stringent and less stringent states, respectively. SIP-regulated power plants will continue to be the predominant source of electric utility emissions thorugh the remainder of this century.

4.1.10 Supplemental Control Technology

Existing boilers can be retrofitted with additional electrostatic precipitators (ESPs) to reduce emissions to the level prescribed for new sources (13 ng/J); the number of fatal cancers is reduced also. EPA's Office of Air Quality Planning and Standards has listed the reduction in particulate emissions that would result from this action (RC83). Table 4.1-16 shows how these reductons can be related to population density.

The number of fatal cancers averted by reducing particulate emissions can be calculated by converting the amount of particulate emissions to curies of uranium-238 released and using the relationship between curies of uranium-238 emitted per year and the number of potential fatal cancers per year. The results are shown in Table 4.1-17. Thus, by retrofitting all existing utility boilers to reach levels of 13 ng/J, about one potential fatal cancer may be averted per year.

Table 4.1-16. Relationship of particulate emissions reduction to population density

Population density[a]	Generating capacity (MW)	Reduction in particulates to reach control level of 13 ng/J (10^4 tons/y)
0-50,000	8,070	2.5
50,000-100,000	7,040	2.1
100,000-250,000	7,140	2.2
250,000-500,000	43,820	13.3
500,000-1 million	82,840	25.3
1 million-2.5 million	72,700	22.2
2.5 million-5 million	31,080	9.5
5 million-10 million	15,430	4.7
Total	268,100	81.8

[a] Population within 80 km of a coal-fired utility boiler.
Source: (RC83).

Cost of Reduced Impact

EPA's Office of Air Quality Planning and Standards has estimated the costs of retrofitting all existing coal-fired utility boilers with control devices to reduce particulate emissions (RC83). To reach a control level of 13 ng/J would result in a capital cost (1982 dollars) of about $13 billion and an annual cost of about $3.4 billion.

Table 4.1-17. Number of fatal cancer averted by reducing particulate emissions

Population density	Reduction in uranium-238[a] emissions (Ci/y)	Number of fatal cancers averted (per Ci/y)	Total number of fatal cancers averted
0-50,000	0.2	3E-3	5E-4
50,000-100,000	0.2	5E-3	1E-3
100,000-250,000	0.2	2E-2	4E-3
250,000-500,000	1.2	3E-2	4E-2
500,000-1 million	2.3	6E-2	1E-1
1 million-2.5 million	2	2E-1	4E-1
2.5 million-5 million	0.9	4E-1	4E-1
5 million-10 million	0.4	8E-1	3E-1
Total	7		1

(a)These values are calculated by converting the reduction of particulates released in tons/year to grams/year, multiplying by the average concentration of uranium-238 in fly ash (9 pCi/g), and converting to curies (1 Ci = 10^{12} pCi).

REFERENCES

Be78	Beck, H.L., et al., 1978, Perturbations of the National Radiation Environment Due to the Utilization of Coal as an Energy Source, Paper presented at the DOE/UT Symposium on the Natural Radiation Environment III, Houston, Texas, April 23-28, 1978.
EPA80a	Environmental Protection Agency, National Emissions Data System Information, EPA 450/4-80-013, EPA, Office of Air Quality Planning and Standards, Research Triangle Park, N. C., July 1980.
EPA80b	Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into the Air in the United States, EPA 520/7-79-006, EPA, Office of Radiation Programs, Washington, D.C., 1980.
EPA81	Environmental Protection Agency, The Radiological Impact of Coal-fired Industrial Boilers, EPA, Office of Radiation Programs, Washington, D.C., (Draft Report), 1981.
RC83	Radian Corporation, Boiler Radionuclide Emissions Control: The Feasibility and Costs of Controlling Coal-fired Boiler Particulate Emissions, Prepared for the Environmental Protection Agency, January 1983.
Re83	Memorandum from T. Reavey, EPA, Office of Radiation Programs, to T. McLaughlin, EPA, Office of Radiation Programs, Washington, D.C., February 1983.
Sm80	Smith, R.D., The Trace Element Chemistry of Coal during Combustion and the Emissions from Coal-Fired Plants, Progress in Energy and Combustion Science 6, 53-119, 1980.
TRI81	Teknekron Research, Inc., Draft Background Information Document, Coal-fired Electric Generating Stations, EPA Contract 68-01-5152, April 1981.
Wa82	Wagner P. and Greiner N. R., Third Annual Report, Radioactive Emissions from Coal Production and Utilization, October 1, 1980-September 30, 1981, LA-9359-PR, Los Alamos National Laboratory, Los Alamos, N. M., 1982.

4.2 Industrial Boilers

4.2.1 General Description

Coal-fired industrial boilers (CFIBs) are used mainly to produce process steam, generate electricity (for the producer's own use), and provide space heat. The boilers are used in virtually every industry from small manufacturing plants to large production concerns. The major users are the steel, aluminum, chemical, and paper industries. Of the coal consumed by industrial boilers in 1974, more than 87 percent was used by these four industries alone. A breakdown of the percent of total coal consumed by each industry is given in Table 4.2-1.

Table 4.2-1. Industrial coal consumption, 1974

Industry	Coal consumption (Percent of total)
Chemicals	33
Paper	26
Steel and aluminum	28
Food	10
Other manufacturing	3

Source: (TRI81).

4.2.2 Process Description

Types of Boilers

Three basic types of boilers are used in the industrial sector: (1) water tube, (2) fire tube and, (3) cast iron.

Water tube boilers are designed so that water passes through the inside of tubes that are heated externally by direct contact with hot combustion gases. The process produces high pressure, high temperature steam with a thermal efficiency of about 80 percent. Water tube boilers range in capacity from less than 3 MW to over 200 MW thermal input.

Fire tube boilers are designed to allow the hot combustion gas to flow through the tubes. Water to be heated is circulated outside the tubes. The boilers are usually smaller than 9 MW thermal input.

Cast iron boilers are designed like fire tube boilers with heat transfer from hot gas inside the tubes to circulating water outside the tubes, but cast iron is used rather than steel. Cast iron boilers are generally designed for capacities less than 3 MW.

Number and Capacity of Boilers

Table 4.2-2 lists the number of boilers and their total installed capacity (EPA81). Water tube units represent 89 percent of the total installed capacity of all boilers in terms of the thermal input. Since the capacity (amount of coal burned) influences the level of emissions to the environment, the radiological impact of coal-fired industrial boilers will be that associated with emissions from water tube type units. Cast iron and fire tube units will not be considered further in this report.

Table 4.2-2. Number and capacity of coal-fired industrial boilers

Boiler type	Unit capacity (MW thermal input)				
	0-3	3-15	15-30	30-75	75 plus
Water Tube Units	683	2309	1290	1181	423
Total MW	835	22225	27895	50825	59930
Fire Tube Units	8112	1224			
Total MW	5650	7780			
Cast Iron Units	35965				
Total MW	6330				

Coal-Firing Mechanisms

There are two main types of coal-fired water tube boilers: pulverized coal and stoker-fired. Pulverized coal units burn coal while it is suspended in air. Units range in sizes from 30 MW to over 200 MW heat input. A stoker unit has a conveying system that serves to feed the coal into the furnace and to provide a grate upon which the coal is burned. Stokers are generally rated at less than 120 MW heat input. The three main types of stoker furnaces are spreader, overfeed (or chain grate), and underfeed. Each of the boiler types is discussed below.

Pulverized coal-fired boilers

Coal is pulverized to a light powder and pneumatically injected through burners into the furnace. If the furnace is designed to operate at a high temperature (typically 1600° C), the ash remains in a molten state until it collects in a hopper at the bottom of the furnace. The high temperature units are known as "wet bottom" units.

"Dry bottom" units operate at lower combustion temperatures with the bottom ash remaining in the solid state. Combustion temperatures initially reach about 1200-1600° C.

Spreader stoker

Coal is suspended and burned as a thin, fast-burning layer on a grate, which may be stationary or moving. Feeder units are used to spread the coal over the grate area, and air is supplied over and under the grate to promote good combustion.

Overfeed stokers

Coal is fed down from a hopper onto a moving grate that enters the furnace. Combustion is finished by the time the coal reaches the far end of the furnace, and ash is discharged to a pit.

Underfeed stokers

Coal may be fed horizontally or by gravity, and the ash may be discharged from the ends or sides. Usually the coal is fed intermittently to the fuel bed with a ram, the coal moving in what is in effect a retort, and air is supplied through openings in the side grates.

Particulate Emissions by Boiler Type

The fractional distribution of ash between the bottom ash and fly ash directly affects the particulate emissions rate and is a function of the following parameters:

Boiler firing method. The type of firing is the most important factor in determining ash distribution. Stoker-fired units emit less fly ash then pulverized coal-fired boilers.

Wet or dry bottom furnaces. Dry bottom units produce more fly ash.

Boiler load. Particulate emissions are directly proportional to the amount (load) of coal burned.

4.2.3 Control Technology

Radionuclides are removed from flue gas with the particulates. The following paragraphs discuss technologies commonly used to remove particulates.

Electrostatic Precipitators

Particle collection in an electrostatic precipitator (ESP) occurs in three steps: (1) suspended particles are given an electric charge,

(2) the charged particles migrate to a collecting electrode of opposite polarity where they are collected, and (3) the collected particulates are dislodged from collecting electrodes. Energy is needed to operate the precipitator in amounts equivalent to 0.02 to 0.1 percent of the fuel energy input to the boiler. ESP efficiency varies with a number of factors, of which particle size is most significant. Table 4.2-3 shows typical efficiences.

Table 4.2-3. ESP collection efficiency as a function of particle size

Particle diameter (micrometer)	Average collection efficiency (Percent)
0-5	72
5-10	94.5
10-20	97
20-44	99.5
Greater than 44	100

Fabric Filter

In fabric filtration, particle-laden flue gas is passed through the fabric to trap particles; the cleaned gas passes through the fabric into the atmosphere.

Energy is required to operate equipment, such as fans, cleaning equipment, and the ash conveying system. The energy requirement depends on the type of boiler and its capacity; it ranges from 3 to 8 times as great as the energy required for an ESP.

The overall mass collection efficiency of a fabric filter ranges from 99 to 99.9 percent with an average of roughly 99.7 percent. Fabric filter control efficiency is not affected by changes in coal sulfur and alkali content, variables which can signicantly affect ESP performance. The efficiency of the fabric filter is also not sensitive to the inlet particle size distribution.

Wet Scrubber

Scrubbers operate on the principle of capturing particulates by bringing them into contact with liquid droplets or wet scrubber walls. They require significant amounts of energy to operate fans and liquid pumps. The energy requirements, which range from 0.2 to 0.7 percent of the fuel energy input to the boiler, depend on the type of boiler and its capacity, characteristics of coal consumed, and level of particulate matter control.

The control efficiency of wet scrubbers is a function of system pressure drop and inlet particle size distribution. Typical collection efficiencies, as a function of pressure drop are shown in the Table 4.2-4.

Table 4.2-4. Typical wet scrubber efficiency

Pressure drop (KPa)	Overall collection efficiency (percent)
1.24	88-95
2.5	92-97
5.0	95-98
7.5	96-99

Mechanical Collectors

The typical mechanical collector is the cyclone collector. The cyclone collector transforms the velocity of an inlet gas stream into a confined vortex from which centrifugal forces tend to drive the suspended particles to the wall of the cyclone body.

The energy requirements are roughly 1 to 2 1/2 times greater than that of ESPs or about 0.12 percent of the fuel energy input to the boiler.

The level of efficiency of the mechanical collector (cyclone) is much lower than ESPs, fabric filters, or wet scrubbers. Additionally, the mechanical collector becomes less efficient as particle size decreases. Accordingly, they are not used to remove small particules.

4.2.4 Radionuclide Emissions

Radionuclide emission rates from coal-fired industrial boilers have not been measured. However, by knowing the radionuclide concentrations in either fly ash or coal, radionuclide emissions from boilers can be estimated.

Table 4.2-5 lists the estimated emission rates of uranium-238 for several industrial boilers in the paper, steel/aluminum, and chemical industries. These boilers were selected, on the basis of particulate emissions data obtained from EPA's National Emissions Data System, to represent the highest controlled and uncontrolled sources. Uranium-238 emission rates were calculated by using an average value of 9 pCi of uranium-238 per gram of fly ash (EPA81).

Table 4.2-5. Estimated radionuclide emissions for boilers with the highest particulate emission levels

Emission control	Uranium-238 emissions (Ci/y)		
	Paper	Steel/Aluminum	Chemical
None[a]	3E-2	6E-2	5E-2
Mechanical collection	1E-2	3E-2	2E-2
Electrostatic precipitator	1E-2	-	1E-2

[a] Assumes that 50 percent of the particulate matter contains particles too large to enter the lungs.

Table 4.2-6 lists other estimates of uranium-238 emission rates from representative coal-fired industrial boilers. The estimates are based on uranium-238 concentrations in the coal used to fire the boilers (TRI81).

Table 4.2-6. Estimated uranium-238 emission rates for representative coal-fired industrial boilers

Boiler capacity (MW)	Emission control	Particulate matter (ng/J)	Uranium-238 emissions (Ci/y)
9	yes	194	1E-4
	no	782	4E-4
22	yes	172	3E-4
	no	712	1E-3
44	yes	138	4E-4
	no	1850	6E-3
59	yes	129	7E-4
	no	2420	7E-3
118	yes	86	9E-4
	yes	43	4E-4

We estimate the uranium-238 emission rate for the entire population of large (15 MW and greater) coal-fired industrial boilers subject to SIP particulate matter limits to be 3 Ci/y.

4.2.5 Reference Coal-Fired Boiler

We chose the source term of the reference case (see table 4.2-7) industrial boiler to resemble the amount of radionuclides that could be released from a large industrial boiler to air under normal operations. Our source term assumptions were conservative so that our projected radiological impacts should be greater than most, but possibly not all, new and existing industrial boilers. There could be different combinations of plant size, coal radionuclide content, levels of control technology, etc., that would yield a source term approximately equal to the one we selected for the reference case.

The source term was calculated using the same methodology used for utility boilers (see Section 4.1) and reflects the relatively smaller thermal capacity and coal consumption of industrial boilers. Table 4.2-8 lists other characteristics of the reference boiler used in the health impact assessment.

Table 4.2-7. Radionuclide emissions from the reference boiler

Radionuclide	Emissions (Ci/y)
Uranium series:	
Uranium-238	1.0E-2
Uranium-234	1.0E-2
Thorium-230	5.0E-3
Radium-226	7.5E-3
Radon-222	2.5E-1
Lead-210	2.5E-2
Po-212	2.5E-2
Thorium series:	
Thorium-232	4.3E-3
Radium-228	6.5E-3
Actinium-228	4.3E-3
Thorium-228	4.3E-3
Radium-224	6.5E-3
Radon-220	8.3E-2
Lead-212	2.2E-2
Bismuth-212	4.3E-3
Thallium-208	4.3E-3

4.2.6 Health Impact Assessment of Reference Industrial Boiler

The estimated annual radiation doses from the reference industrial boiler are listed in Table 4.2-9. Table 4.2-10 presents estimates of the maximum lifetime risk and the number of fatal cancers to the regional population from these doses.

4.2.7 Total Health Impact of Coal-Fired Industrial Boilers

The estimated total number of fatal cancers caused by all coal-fired industrial boilers is about one per year. This estimate was derived by multiplying the health effects for the reference boiler by the ratio of the total (estimated) uranium-238 emissions of the entire CFIB industry and the reference boiler.

Table 4.2-8. Reference coal-fired industrial boiler

Parameter	Value
Site	Midwest location (St. Louis),
Population	2.5 million people within 80 km of the site
Stack	
Effective height	150 meters
Diameter	1.5 meters

Table 4.2-9. Radiation dose rates from radionuclide emissions from the reference industrial boiler

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	3.4E-1	7.6E+1
Red marrow	4.0E-2	6.6
Kidney	4.0E-2	9.0
Bone	4.3E-1	9.0E+1
Liver	2.0E-2	3.2

Table 4.2-10. Fatal cancer risks due to radionuclide emissions from the reference industrial boiler

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Industrial boiler	1E-6	4E-3

4.2.8 Existing Emission Standards and Air Pollution Control

No Federal or state regulations currently exist that limit emissions of radionuclides from coal-fired industrial boilers. However, the states, through State Implementation Plans (SIPs), and the Federal government, through New Source Performance Standards (NSPS), regulate particulate matter emissions and thus effectively limit radionuclide emissions.

All existing coal-fired industrial boilers are subject to SIPs. Since the individual SIPs reflect local conditions and needs, particulate matter emissions vary from state to state.

All new coal-fired industrial boilers with capacities greater than 73.3 MW (thermal input) are subject to a particulate emission limit of 43.3 ng/J (40 CFR 60, subpart D.) New boilers with capacities less than 73 MW are subject to limits prescribed by the SIPs.

4.2.9 Supplemental Control Technology

Currently, large coal-fired industrial boilers (15 MW and greater), which are subject to SIP particulate matter limits, emit about 0.37 million tons of particulate matter per year. Table 4.2-11 lists the costs, particulate matter emission levels, and cost-effectiveness to retrofit large boilers to meet specific uniform emission levels (RC82).

Table 4.2-12 lists estimated uranium-238 emissions for existing and retrofitted large boilers (15 MW and larger) subject to SIP particulate matter control.

Table 4.2-13 lists estimated current risks and risk reductions for particulate matter limits for large (15 MW and greater) coal-fired industrial boilers.

Table 4.2-11. Estimated costs and particulate matter reductions from retrofit controls for coal-fired boilers[(a)]

Costs	Emission level	
	(0.1 lbs/10^6BTU)	(0.05 lbs/10^6BTU)
Capital Cost	\$2.5 billion	\$3.4 billion
Annual Cost	\$550 million	\$730 million
Particulate matter reduction	0.15 million tons/y	0.19 million tons/y
Cost effectiveness: (\$/ton)	\$3,600	\$3,800

(a) 15 MW and greater boilers.

Table 4.2-12. Estimated uranium-238 emission rates for existing and retrofitted large coal-fired industrial boilers[(a)]

Particulate matter control level rate (lbs/10^6 BTU)	Uranium-238 emission rate (Ci/y)
Various under SIPs	2.9
0.1	1.7
0.05	1.4

(a) 15 MW and greater.

Table 4.2-13. Risks associated with large coal-fired industrial boilers[a]

Particulate matter control level	Risks (Fatal cancers/y)
Various under SIP's	1
0.1	7E-1
0.05	6E-1

[a] 15 MW and greater.

REFERENCES

EPA81 Environmental Protection Agency, The Radiological Impact of Coal-fired Industrial Boilers (Draft), EPA Office of Radiation Programs, Washington, D.C., October 1981.

TRI81 Teknekron Research, Inc., Draft Background Information Document for Coal-Fired Industrial Boilers, May 1981.

RC82 Radian Corporation, Development of Coal Combustion Radionuclide Particulate Emission and Control Cost Information, Draft Report, November 1982.

Chapter 5: URANIUM MINES

5.1 General Description

In uranium mining operations, ore is removed from the ground in concentrations of 0.1 to 0.2 percent U_3O_8 or 280 to 560 microcuries of uranium-238 per metric ton of ore. Since the uranium-238 in the ore is normally present in secular equilibrium with its daughter products, these ores also contain equal amounts of each member of the uranium-238 decay series.

After mining, the ores are shipped to a uranium mill to separate the uranium. Radioactive emissions to air from uranium mines and mills consist of uranium bearing dust and radon-222 gas.

Uranium is mined in both open pit and underground mines. In 1981 there were 167 underground and 50 open pit uranium mines in operation in the United States (Table 5-1). These mines accounted for about 79 percent of the uranium produced (DOE82).

Table 5-1. Distribution of 1981 U_3O_8 production in ore by mining method (DOE82)

Source	Number	Tons U_3O_8 (a)	Percent of total
Underground mines	167	8,500	43
Open pit mines	50	7,000	36
Solution Mining (In-Situ)	14	2,100	11
Others: heap-leach, mine water, byproduct, and low-grade stockpiles	23	2,000	10
Total	254	19,600	100

(a) Short tons

In recent years in-situ solution mining has been more widely used; this method is expected to increase in future years. During 1981 this method accounted for 11 percent of the uranium mined in the United States. The radioactive emissions from this source are small compared to the other sources.

Table 5-2 indicates that at present all uranium is mined in the western United States, mostly in the states of New Mexico, Wyoming, and Texas. Exploration for uranium is being conducted, however, in the eastern and midwestern parts of the United States.

Table 5-2 Distribution of 1981 U_3O_8 production in ore by State (DOE82)

State	U_3O_8 (Short tons)	Percent of total
New Mexico	6,600	34
Wyoming	4,400	22
Texas	3,200	16
Arizona, Colorado, Texas, Utah, & Washington	5,400	28
Total	19,600	100

Major publicly-held corporations account for a large share of ownership in the uranium industry. The industry grew rapidly in the early and mid-1970's, stimulated by expectations of rapid increases in demand. However, the expectations were too optimistic, with supply outstripping demand. The result was an economic slump for the industry. The industry is now faced with excess capacity, large inventories, lower-than-expected demand, and the potential for increased competition from imports.

5.2 Process Description

Underground mining

Underground uranium mining is usually carried out using a modified room and pillar method. In this method, a large diameter main entry shaft is drilled to a level below the ore body. A haulage way is then established underneath the ore body. Vertical raises are driven up from the haulage way to the ore body. Development drifts are driven along the base of the ore body connecting with the vertical raises. Mined ore is hauled along the development drifts to the vertical raises and gravity fed to the haulage way for transport to the main shaft for hoisting to the surface.

Figure 5-1 is an example of an underground mining operation. Ventilation shafts are installed at appropriate distances along the ore body. Typical ventilation flow rates are on the order of 6,000 m^3/min. The principal radioactive effluent in the mine ventilation air is radon-222 which is released during mining operations. Additional radon-222 and particulate (uranium and thorium) emissions result from surface operations at the underground mine.

Surface Mining

Open pit mining usually is carried out by excavating a series of pits in sequence. The topsoil and overburden are removed from above the ore zone and stockpiled in separate piles for use in future reclamation operations. The uranium ore is removed from the exposed ore zone and stockpiled for transport to a uranium mill. Ore stockpiles range in size up to several hundred thousand metric tons of ore. During the mining of the uranium ore, low grade waste rock is also removed from the pits and stored in a waste stockpile for possible future use.

Figure 5-2 is an example of an open pit mining operation. As the mining progresses, mining and reclamation operations take place simultaneously--pits are mined in sequence, and the mined-out pits are reclaimed by backfilling with overburden and topsoil. In some cases, the last of the open pits in a mining operation are not backfilled but are allowed to fill with water, forming a lake. Radioactive emissions from open pit mining operations are radon-222 gas and fugitive dust containing uranium and thorium.

In-Situ Mining

In this method, a leaching solution is injected through wells into the uranium-bearing ore body to dissolve in the uranium. Production wells bring the uranium-bearing solution to the surface where the uranium is extracted. The solution (lixiviant) can be recovered and reused.

Radon-222 gas is emitted from the processing operations and waste piles. With solution mining, less than 5 percent of the radium from an ore body is bought to the surface (EPA82). Consequently, the amount of radon released is considerably less than that from conventional mining. The major sources of radon are the surge ponds, enclosed surge tanks, inplant surge tanks and absorption columns (Br81). It is

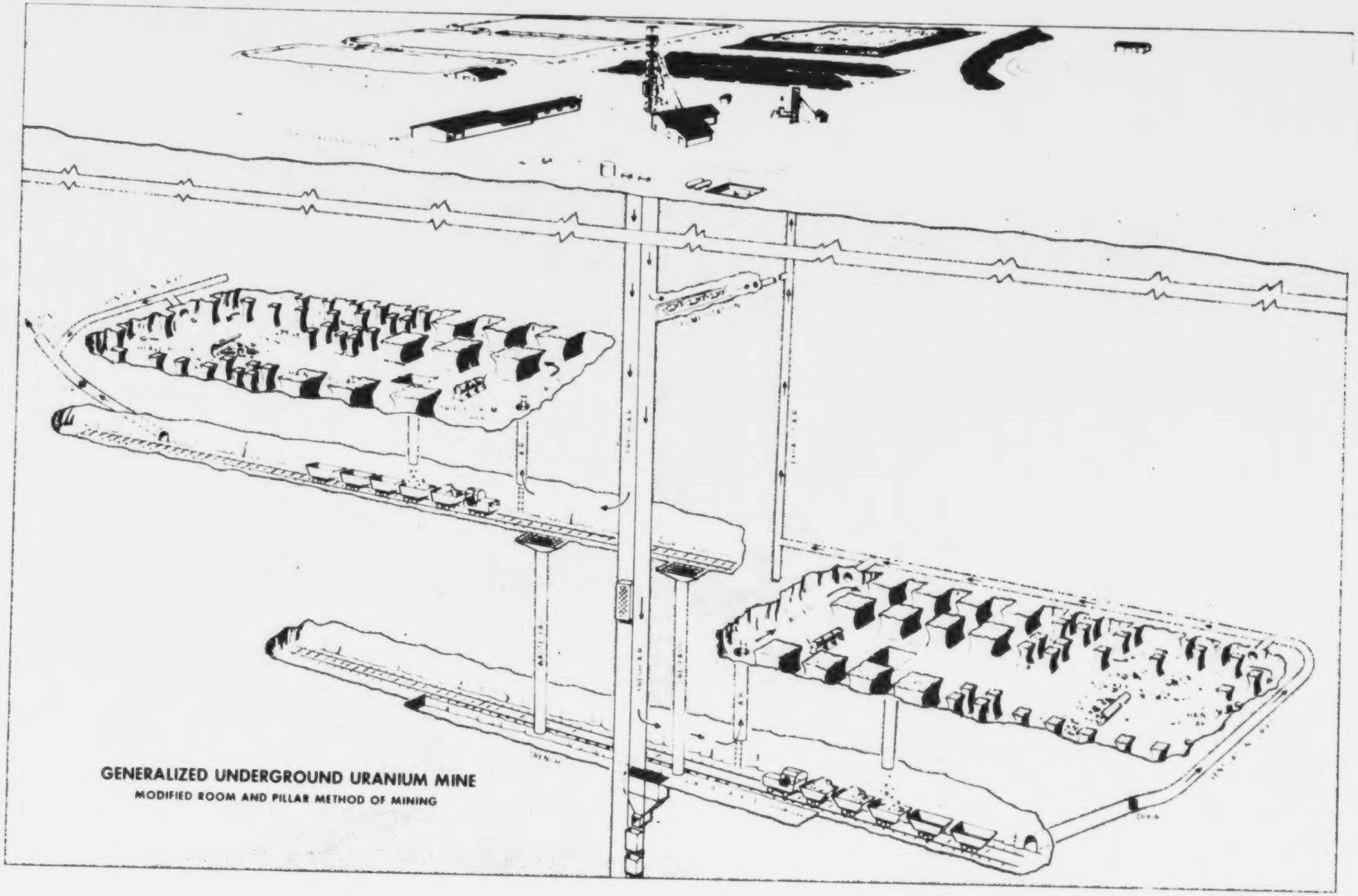

GENERALIZED UNDERGROUND URANIUM MINE
MODIFIED ROOM AND PILLAR METHOD OF MINING

Figure 5.1-1. An underground uranium mining operation.

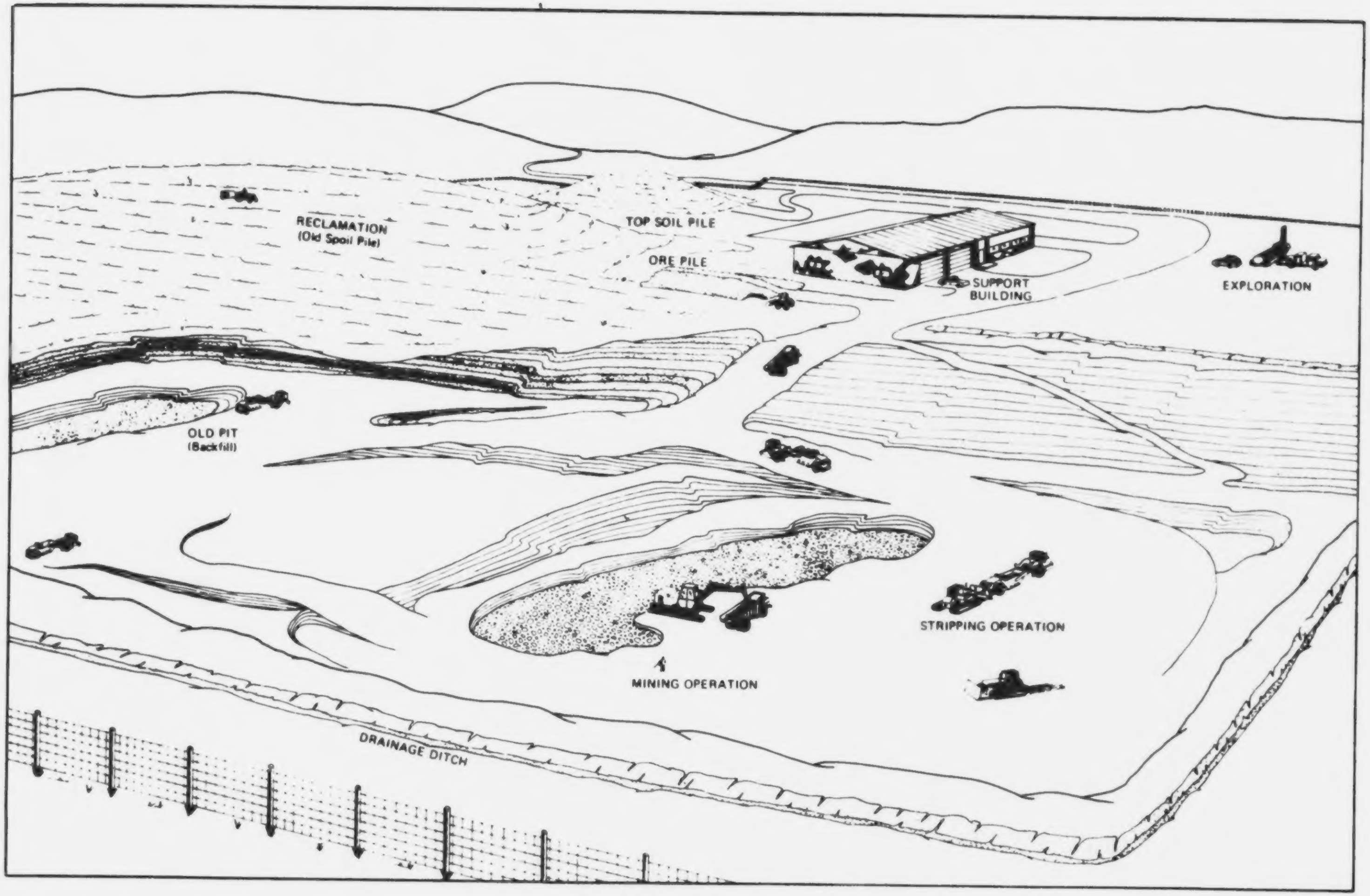

RECLAMATION
(Old Spoil Pile)
TOP SOIL PILE
ORE PILE
SUPPORT BUILDING
EXPLORATION
OLD PIT
(Backfill)
STRIPPING OPERATION
MINING OPERATION
DRAINAGE DITCH

Figure 5.1-2. An open pit uranium mining operation.

estimated that the radon released is about 19 percent of the amount released from a conventional uranium mill (EPA82).

A small amount of radon is released from the waste piles formed as a result of the operation. Some examples of solid wastes that might be generated by the alkaline leach in-situ process are:

(1) Materials filtered from the lixiviant line,
(2) Sediments from the surge tanks,
(3) Calcium carbonate from the calcium control unit,
(4) Barium sulfate from the contaminated control in the elution/precipitation circuit of the recovery process,
(5) Materials deposited in the evaporation ponds,
(6) Drill hole residues,
(7) Solids from aqiufer restoration.

EPA has previously evaluated radionuclide emissions from uranium mining activities (EPA79, EPA83). These evaluations indicate that underground uranium mining releases the largest quantities of radon-222 to air and results in the most significant health impacts when compared to other mining methods. Because of the lower amounts of radon released from surface mines, in-situ solution mining, and other mining methods, the potential health impact of underground uranium mining is of the most concern and therefore, Sections 5.3 through 5.8 of this chapter deal only with underground uranium mines.

5.3 Control Technology

Several methods to control radon emissions from underground uranium mines have been evaluated. These are: 1) use of sealant coating on exposed ore surfaces; 2) bulkheading of worked-out areas; 3) activated carbon adsorption of radon from contaminated mine air; 4) mine pressurization; and 5) miscellaneous technologies.

Sealant Coating

One of the the best methods for controlling radon in an underground uranium mine is to prevent radon from entering the mine air by sealing exposed surfaces. A summary of field tests and a review of the literature on this subject performed for EPA (Ko80) is summarized as follows:

1) Under laboratory conditions sealants are very effective in attenuating radon emissions from ore surfaces, but in an actual mine application, the presence of "pinholes" and the difficulty of applying a perfect coating on an ore surface reduces the effectiveness of these sealants considerably.

2) In field tests a three-coat system of HydroEpoxy 156 and HydroEpoxy 300, preceded by Shotcrete base coating, was found to

be effective (50 to 75 percent radon stoppage). For the theoretical mine, the sealant probably would be 60 percent effective with an eight-month lifetime.

3) The amount of sealants used varied considerably for different mines. Kown and his associates (Ko80) chose the following amounts for their study which were greater than other studies on this subject.

Shotcrete	-	909 gal per 1000 ft^2
HydroEpoxy 156	-	18 gal per 1000 ft^2
HydroEpoxy 300	-	32 gal per 1000 ft^2

4) The sealant coating applied to drifts of an underground mine have a limited life of about eight months because the drift area is mined after pillars are extracted in a room-and-pillar stope mine.

5) An asphalt emulsion sealant has been tested in the laboratory and on tailing piles and is found to be an effective, inexpensive sealant. However, it has not yet been tested in an underground mine atmosphere.

The cost of coating 530,000 ft^2 of drift surfaces in the mine was $344,300 ($1.45 per ton of ore removed). The floors were not considered to be coated because ore loaders will destroy the coating on the semiconsolidated muck. The three sealants were applied every two months. Cost estimates of other sealants range from $0.30 to $1.10 per square foot which is comparable to the sealants used in this study (Fr81).

This EPA study has shown that sealants could reduce the radon emanation from the active stopes of the mines by 23 percent. If the total mine is included (25 extracted stopes), only 11 percent of the radon was reduced. This second figure should be used when determining the amount of radon released from the mine. Other studies by the Bureau of Mines (Fr81) have shown that 50 to 75 percent of the radon can be retained in the rock by sealants.

Bulkheading

Bulkheading of mined-out areas, such as extracted stopes, is the most common radon control method currently practiced in underground mines (Ko80). In general, it is used to isolate worked-out areas or stopes from workers so that the radon concentrations in the working areas of the mine will be lower. If the bulkhead is air tight, the radon behind the barrier will decay to innocuous levels. However, all bulkheads leak to some extent, and usually a small 3- to 6-inch pipe is used as a bleeder pipe to provide negative pressure in the extracted stope (Fr81) and to allow the contaminated air to be diverted to the ventilation system. A small fan may be required to maintain the negative pressure. Ideally, only 10 percent of the air behind the bulkhead would be diverted to the outside atmosphere. This air stream can also be connected to an activated carbon filter or trap to reduce concentrations further.

In an EPA study (Ko80) it was assumed that 12.5 stopes per year would be sealed using 100 bulkheads. The cost for material, labor, and maintenance was estimated to be $80,400 or $0.34 per ton of ore removed. It was also assumed that a six-inch pipe provided a 100 cfm bleeding rate from each bulkheaded area.

An estimate of the effectiveness of reducing radon by this system was made using many crude assumptions. For the total mine, bulkheading was estimated to achieve about a 14 percent reduction in radon emissions. A small preliminary study conducted by Battelle on an actual mine indicated that a radon reduction of 35 percent could be obtained by using bulkheads (Dra80).

Radon Adsorption on Activated Carbon

Leakage of high radon concentrations through bulkheads used to control radon concentrations in mines is another problem. One method to relieve this problem is to insert a small bleeder pipe in the bulkhead to provide negative pressure within the enclosed area behind the bulkhead. This bleeder pipe is usually connected to the exhaust ventilation system. Although this may prevent exposure to the workers, the radon emissions to the environment may still be high. An activated carbon adsorption system may be attached to the radon effluent pipe before releasing this air to the exhaust ventilation system (Ko80).

An effective radon cleanup system for the bleeder pipes is still under study. The system chosen by investigators in an EPA study (Ko80) is shown in Figure 5-3. It consists of two carbon adsorption systems in series. The flow from the bleeder pipe is filtered to remove dust particles and radon daughter products. The radon is then adsorbed in the carbon column. The carbon column is regenerated once a day, using hot air. The contaminated air from the regeneration is sent through a second carbon column to again adsorb the radon gas. Occasional drying may be required in the second column due to buildup of moisture.

In evaluating control technology in a model mine, EPA (Ko80) found that an average of 12.5 activated carbon systems must be installed each year to treat the contaminated air from the stopes sealed by the bulkheads. The capital and operating costs for each unit is as follows:

Capital Cost of Each Unit

Major equipment	$22,000
Auxiliaries & Installation	$11,000
	$33,000

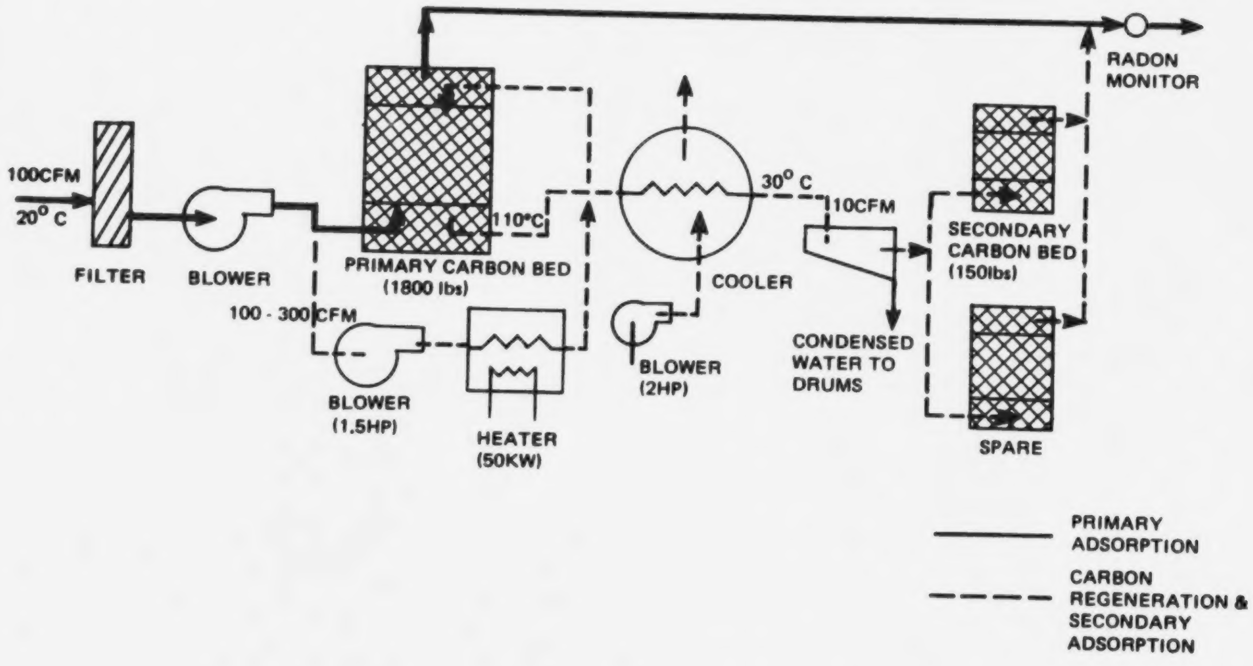

100CFM
20° C
FILTER
BLOWER
PRIMARY CARBON BED
(1800 lbs)
110°C
100 - 300 CFM
BLOWER
(1.5HP)
HEATER
(50KW)
30° C
COOLER
BLOWER
(2HP)
10CFM
CONDENSED
WATER TO
DRUMS
SECONDARY
CARBON BED
(150lbs)
SPARE
RADON
MONITOR
PRIMARY
ADSORPTION
CARBON
REGENERATION &
SECONDARY
ADSORPTION

Figure 5.1-3. Radon removal from mine air by carbon adsorption.

Annual Cost of Each Unit

Material (carbon, filters, piping)	$ 1,000
Utilities ($25,000 kwh @ 4¢/kwh)	$ 1,000
Labor (0.25 man-year)	$ 8,000
Amortizing (an avg. 5-year life at 10% interest)	$ 8,700
Total	$18,700

Assuming the lifetime of each unit is 5 years and 12.5 units per year are needed, the annual cost over five years would be $233,750 or $4.32 per ton of ore mined. The carbon system was assumed to be 95 percent efficient in removing radon.

The effectiveness of the entire system, including bulkheading and carbon traps, was estimated to be 49 percent. A study by Battelle (Dra80) estimates a 45-68 percent effectiveness, using absolute sorption traps in combination with bulkheading. The total cost for bulkheading and carbon traps would be $4.66 per ton of ore mined.

There are some definite disadvantages to the carbon adsorption system. Skilled operators, usually not available in mining communities, are necessary to operate and maintain the system. Safety problems to the miners are possible due to interrupted electrical service or system malfunction. Excess radon concentrations would then be present. The carbon columns would have to be shielded to prevent gamma exposure to the miners.

The system does appear to be technically feasible utilizing commercial carbons and standard equipment. However, additional developmental work is necessary before such a system can be used in a mine environemt.

Mine Pressurization

Positive mine pressurization has been tried several times to force the radon in the mine atmosphere back into the walls of the mine (Ko80 and Fr81). In general, these efforts have been successful in reducing the radon concentrations in the mine itself. An "air" sink is necessary to accept the radon. If the radon is forced through the ore body or surrounding area to the surface, the radon can decay before coming to the surface. If the area is impermeable however, radon levels will return to previous levels. In the latest tests (Fr81), the radon levels in the mine were reduced by 20 percent; releases to the atmosphere were not determined. The surrounding area needs to be permeable enough to reduce gas flow to the surface and also to allow decay of the radon (Ko80). The costs of mine pressurization are not available because the process is in a development stage.

Miscellaneous Radon Control Technology

Argonne National Laboratory is experimenting with strong oxidizing agents, such as bromine triflouride and dioxygenyl hexaflouro-antimonate, to convert the radon to another form that can be absorbed on a scrubber or absorption bed (Fr81). However, the corrosive and toxic nature of the reactants makes their use in mines impracticable and questionable.

Backfilling of worked-out areas is practiced by mine operators to get rid of excess tailings from the mine and/or mill (Fr81). This procedure is used mainly for ground support and to reduce ventilation requirements. A study, by the Bureau of Mines and Kerr-McGee Nuclear, to determine the effectiveness of reducing radon emissions by backfilling mill tailings into the mine stopes indicated a radon reduction of 57 percent in exhaust air (Fr81). However, radioactive and nonradioactive contamination of mine water was increased due to seepage from the tailing slurry.

Increasing the height of vents is a possible method to reduce ground level radon concentrations in ambient air (Dra80). One of the conclusions based on a theoretical model was that "a 20-meter release height reduces the annual average concentration (when compared to a ground-level release) by about 60 percent at one mile from a source and by about 30 percent at ten miles from the source." A preliminary estimate of cost is about $35,000 for a 20-meter stack (B183). The average number of vents for a mine is about 6 (Ja80). Thus, the cost per mine would be about $210,000 or $.40 per ton of ore produced.

Summary of Costs and Efficiencies

A summary of the costs and efficiencies of the various radon control technologies is shown in Table 5-3.

Table 5-3. Cost and efficiencies of radon control technologies for underground uranium mines

Method	Radon reduction (Percent)	Cost ($/ton of ore)
Sealant coating	11	1.45
Bulkheading	14	0.34
Activated carbon	35	4.32
Bulkheading with activated carbon	49	4.66
Mine Pressurization	20-25	-
Stacks	60(a)	0.40
Backfilling	57	-

(a)Reduction in exposure to maximum individual.

Table 5-4. Summary of measurements of radon-222 emissions from underground uranium mine vents (Ja80)

Mine	Number of vents	Ore production (tons/d)[a]	Ore grade % U_3O_8	Years in production	Radon-222 emissions (Ci/y)[b]
A	4	2190	0.19	3	7,400
B	6	712	0.24	9	4,500
C	6	946	0.21	9	4,600
D	2	1070	0.20	7	3,630
E	14	1000	0.16	21	29,800
F	15	715	0.19	20	9,400
G	5	794	0.18	4	1,800
H	10	480	0.10	21	15,200
I	11	300	0.12	-	1,690
J	12	368	0.19	20	7,900
K	4	352	0.47	19	6,400
L	9	250	0.06	29	1,400
R	11	114	0.18	20	14,800
T	5	420	0.20	-	1,890
U	3	500	0.15	4	890
V	2	550	0.11	2	1,010
Y	7	2630	0.15	6	17,500
Z	3	500	0.14	1[illegible]	2,640
AA	3	-	-	-	1,800
BB	8	-	-	-	2,000
CC	3	-	-	-	2,120
DD	2	-	-	-	960
EE	5	-	-	-	6,500
FF	3	-	-	-	2,510
GG	3	150	0.16	-	170
HH	2	-	-	-	1,040
II	2	-	-	-	470
Average	6	740	0.18	13	5,600

(a)Based on 1978 survey of mines.

(b)Average of data from measurements made in 1978 and 1979.

5.4 Radionuclide Emission Measurements

Radon-222 is the radionuclide emitted from underground uranium mines which causes the greatest risk to people. The major source of radon-222 emissions to air are the mine vents through which the ventilation air is exhausted. A large underground mine will usually have several vents; some mines have as many as 15 vents. Radon-222 emissions from these vents are highly variable and depend upon many interrelated factors including: ventilation rate, ore grade, production rate, age of mine, size of active working areas, mining practices, and several other variables.

Pacific Northwest Laboratories (PNL) has measured the radon-222 emissions from 27 underground uranium mines (Ja80) (Table 5-4). The average radon-222 emission rate for these 27 mines was 5,600 curies/year.

In addition to the mine vents, radon-222 is emitted to air from several above-ground sources at an underground uranium mining operation. These sources are the ore, subore, and waste rock storage piles. PNL has estimated the radon-222 emissions from these sources to be about 2 to 3 percent of the emissions from the vents (Ja80). EPA has estimated the emissions from the above-ground sources to be about 10 percent of mine vent emissions (Table 5-5).

The above-ground sources also emit radionuclides to air as particulates. The particulate emissions result from ore dumping and loading operations and wind erosion of storage piles. EPA has estimated that about 2E-2 Ci/y of uranium-238 and 3E-4 Ci/y of thorium-232 and each of their decay products would be emitted into the air at a large underground mine (EPA83). An assessment of the health

Table 5-5. Estimated annual radon-222 emissions from underground uranium mining sources (EPA83)

Source	Average large mine[(a)] (Ci/y)
Underground	
Mine vent air	3,400
Aboveground	
Ore loading and dumping	15
Sub-ore loading and dumping	5
Waste rock loading and dumping	0
Reloading ore from stockpile	15
Ore stockpile exhalation	53
Sub-ore pile exhalation	338
Waste rock pile exhalation	3
Total	3829

(a) Ore grade = 0.1% U_3O_8. Annual production of ore and sub-ore = 2×10^5 MT, and waste rock = 2.2×10^4 MT.

risks from these emissions showed that the risks from the particulate emissions were much smaller (a factor of 100 less) than the risks from radon-222 emissions (EPA83). Therefore, the health risk assessment presented in the subsequent sections of this chapter will be limited to radon-222 emissions.

5.5 Reference Underground Uranium Mine

Table 5-6 describes the parameters of the reference mine which are used to estimate the radon-222 emissions to the atmosphere and the resulting health impacts. These parameters were chosen primarily from information in Table 5-4. The reference mine has 5 vents in the configuration as shown in Figure 5-4.

The radon-222 emissions to air from the reference underground mine are listed in Table 5-7. These emissions are based on information in Table 5-4 and on the aboveground percent emissions from Table 5-5. In the reference mine, each of the mine vents is assumed to emit the same quantity of radon-222.

Table 5-6. Reference underground uranium mine

Parameter	Value
Ore grade	0.18% U_3O_8
Ore production	1.7E+5 MT/y
Days of operation	250 days/y
Number of vents	5
Vent height	3 meters

Table 5-7. Radionuclide emissions from the reference underground uranium mine

Source	Emissions (Ci/y)
	Radon-222
Mine vents[(a)]	5,000
Ore, subore and waste rock piles	500
Total	5,500

(a)1,000 Ci/y from each vent.

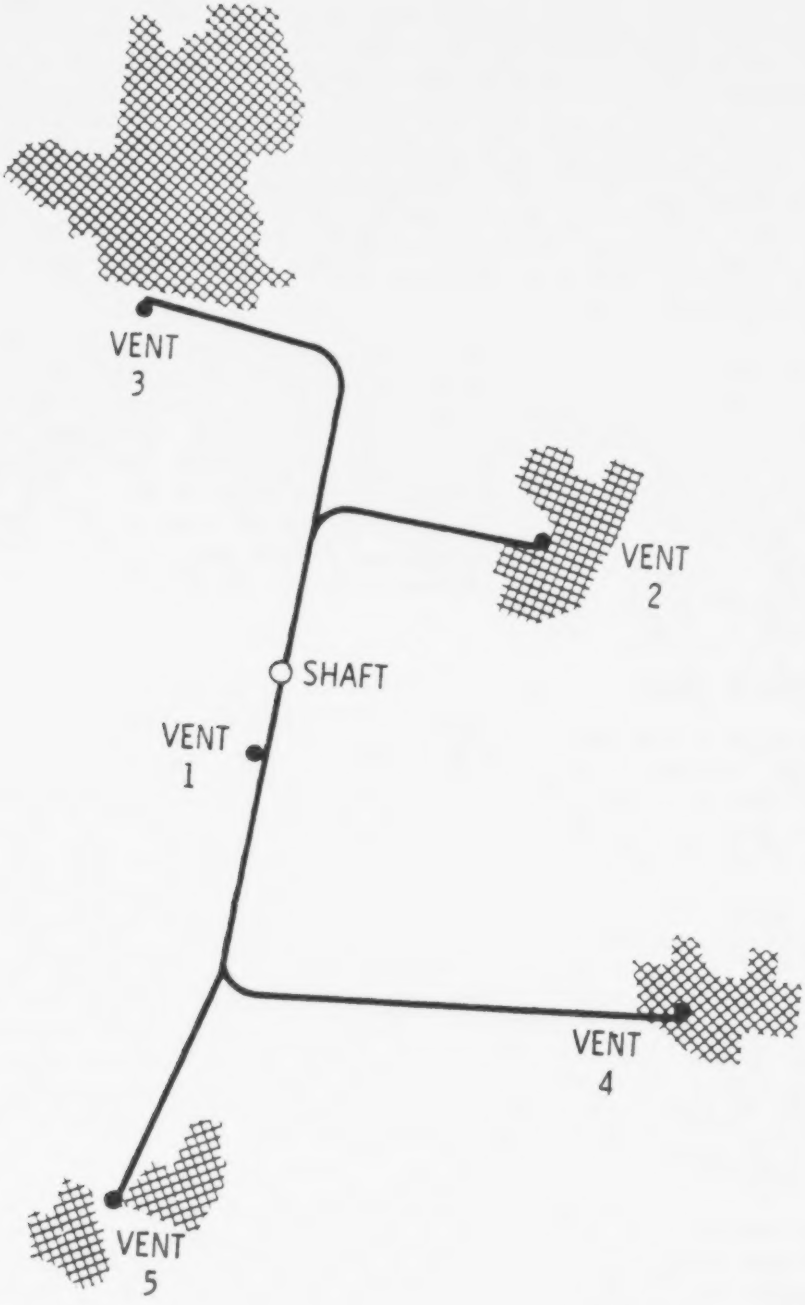

VENT
3
VENT
2
SHAFT
VENT
1
VENT
4
VENT
5

Figure 5-4. Reference underground mine.

5.6 Health Impact Assessment of the Reference Underground Uranium Mine

The lifetime risk to nearby individuals and the number of fatal cancers per year of operation due to radon-222 emissions from the reference underground uranium mine are presented in this section.

The risks to individuals are treated in more detail than the population risks because the individual risks can be relatively high for people living near the mine. These exposures generally occur in structures built around the mines. Radon-222 enters the building and decays into other radionuclides which become attached to dust particles in the air. The concentration of these radionuclides build up in the air within the structures.

EPA estimated the health risks from radon-222 emissions from uranium mines using the general assumption discussed in Appendix B. It is important to recognize that the actual risk to individuals may differ from these estimates because the circumstances involving the exposure may differ significantly from the assumptions used to make the estimates. For example, because mines have a limited lifetime (10 to 20 years), the period of exposure is likely to be less in real cases than assumed in the models. Furthermore, people need to be occupying a structure and not just standing outdoors for these estimates to be applicable.

Individual Risks

In assessing the health risks to individuals living near underground uranium mines, an evaluation was made of (a) the radon-222 emissions from a single vent, (b) a series of vents from a single mine, (i.e., the reference mine), and (c) multiple vents from multiple mines which are close together.

Estimates of the radon-222 concentration at various distances from an underground uranium mine vent emitting 1000 Ci/y of radon-222 are shown in Table 5-8. Also shown in this table are the estimated individual lifetime risks of fatal cancer from the inhalation of radon-222 decay products produced (inside a house) by these radon-222 concentrations. Similarly, Table 5-9 shows the estimated radon-222 concentrations in air and the individual lifetime risks of fatal cancer at various distances from the reference underground uranium mine (i.e., 5 mine vents distributed as shown in Figure 5-4 and each emitting 1000 Ci/y of radon-222).

The radon-222 concentration in air at any specific location near a uranium mine with multiple vents is highly dependent upon the spatial distribution of the vents with respect to the location of interest and the wind frequency distribution. The data in Table 5-9 illustrate the levels which could occur in a given situation. For other situations (i.e., different spatial distributions of the vents, wind frequencies, etc.), the radon-222 concentrations in air could be higher or lower than the values shown in Table 5-9.

Table 5-8. Estimates of radon-222 concentrations in air and individual lifetime risks at selected distances from an underground uranium mine vent(a)

Distance (meters)	Maximum(b)		Average(c)	
	Radon-222 (pCi/L)	Individual lifetime risk	Radon-222 (pCi/L)	Individual lifetime risk
100	8.9	1E-1	2.7	3E-2
200	5.4	6E-2	1.5	2E-2
500	1.3	2E-2	0.37	4E-3
1,000	0.38	5E-3	0.11	1E-3
2,000	0.12	1E-3	0.03	4E-4
3,000	0.06	7E-4	0.017	2E-4
5,000	0.03	4E-4	0.009	1E-4
10,000	0.01	1E-4	0.003	4E-5

(a)The lifetime risks were estimated using the relationship that 1 pCi/L of radon-222 in air results in a radon-222 decay product concentration of 0.007 working levels inside a house.

(b)Predominant wind direction.

(c)Average of all wind directions.

Table 5-9. Estimates of radon-222 concentrations in air and individual lifetime risks at selected distances from the reference underground uranium mine(a)

Distance (meters)(c)	Maximum		Average	
	Radon-222(b) (pCi/L)	Individual lifetime risk	Radon-222(b) (pCi/L)	Individual lifetime risk
500	1.5	2E-2	0.60	7E-3
1,000	0.54	6E-3	0.27	3E-3
2,000	0.24	3E-3	0.11	1E-3
3,000	0.18	2E-3	0.07	8E-4
5,000	0.12	1E-3	0.04	5E-4
10,000	0.06	7E-4	0.015	2E-4

(a)The lifetime risks were estimated using the relationship that 1 pCi/L of radon-222 in air results in a radon-222 decay product concentration of 0.007 working levels inside a house.

(b)The data used to estimate these concentrations and examples of the method of calculation are shown in Appendix C. The concentrations listed under the heading "maximum" are believed to be the highest concentrations which would occur at these distances for the configuration of mine vents postulated and the meteorology used.

(c)The distance from mine vent 5 in southeasterly direction which is the predominant wind direction (See Figure 5-4).

To evaluate the extent to which emissions from multiple mines located close together will influence the radon-222 concentrations in air, PNL carried out a modeling study using the Ambrosia Lake District of New Mexico as a "case study" (Drb81). Using a Gaussian diffusion model, estimates were made of the radon-222 concentrations in air resulting from emissions from 117 mine vents. Figure 5-5 shows the distribution of mine vents used in the study and Figure 5-6 the computed radon-222 concentration (above background) in air for this region. Although these computed concentrations are only approximate values due to the many complexities of this type of modeling study, the results of this study indicate that the radon-222 concentrations in an intensive underground uranium mining area will be significantly elevated above background. The vents are also the greatest sources of the radon concentrations in the immediate area of mining and milling activities. The study shows that, in areas surrounded by mine vents, the radon-222 concentrations may range up to 12pCi/L above background.

Population Risks

The radon decay product exposures and the number of fatal cancers per year of operation for the reference underground uranium mine are shown in Table 5-10. These estimates are for a site near Grants, New Mexico, with a regional population of 36,000. The number of fatal cancers per year of operation of the reference mine is estimated to be 0.03 to the regional population and 0.07 to the national population.

Table 5-10. Annual radon-222 decay product exposures and number of fatal cancers to the population from radon-222 emissions from the reference underground uranium mine

Source	Regional population		National population	
	(Person-WL-y)	(Fatal cancers/y of operation)	(Person-WL-y)	(Fatal cancers/y of operation)
Underground uranium mine	1.1	3E-2	3.1	7E-2

5.7 Health Impact from Underground Uranium Mining

An estimate of the total health impact from radon-222 emissions from all underground uranium mining (using production values for 1981) may be made by multiplying the number of fatal cancers caused by emissions from the reference mine by the ratio of the amount of uranium produced by all underground mines to the amount produced by the reference mine. This estimate for the regional population was 0.7 fatal cancers/year and for the national population was about 2 fatal cancers/year.

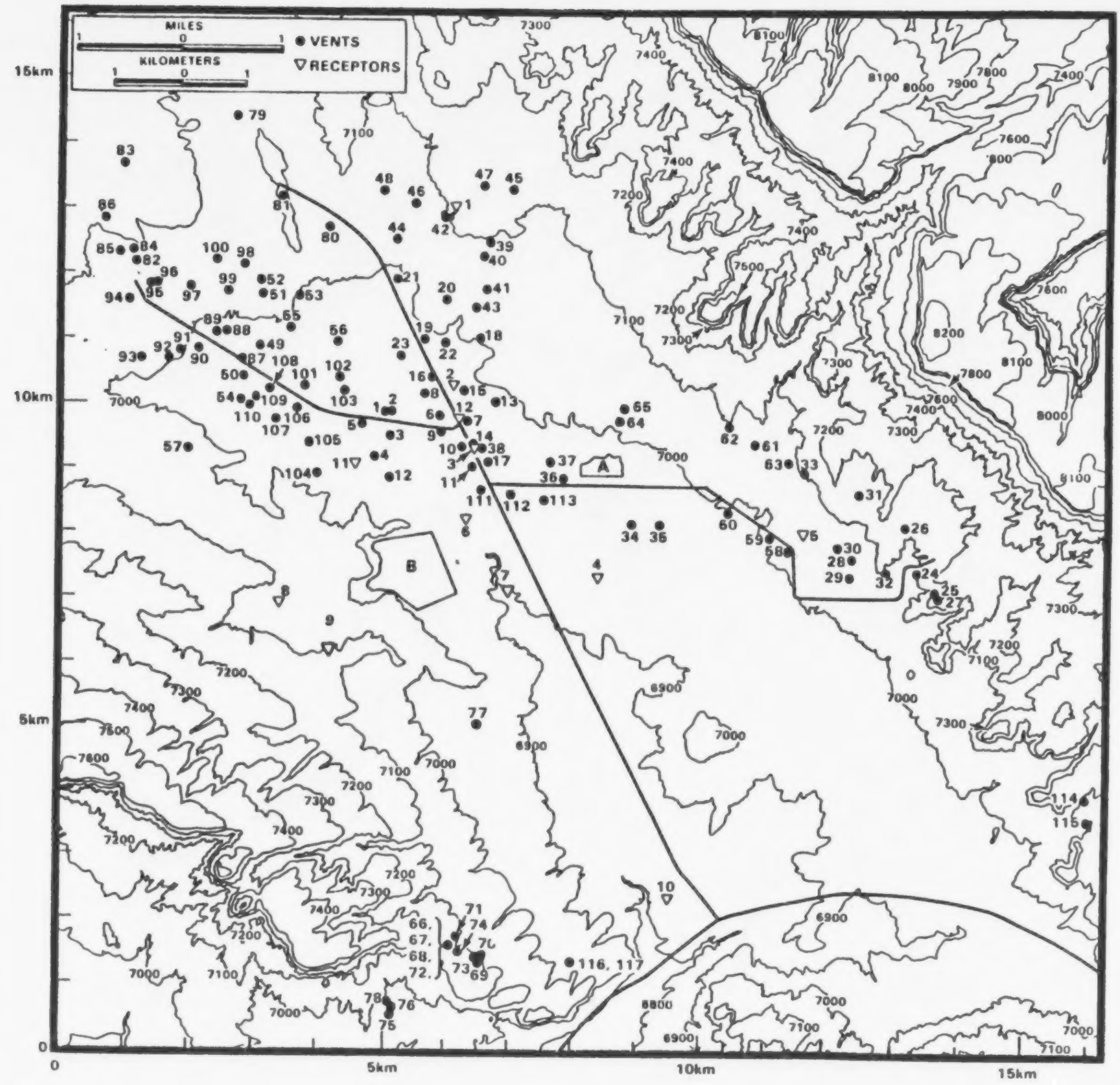

MILES
1 0 1
KILOMETERS
1 0 1
● VENTS
▽ RECEPTORS
15km
10km
5km
0
5km
10km
15km
A
B

Figure 5-5. Detailed map of mining area showing source.

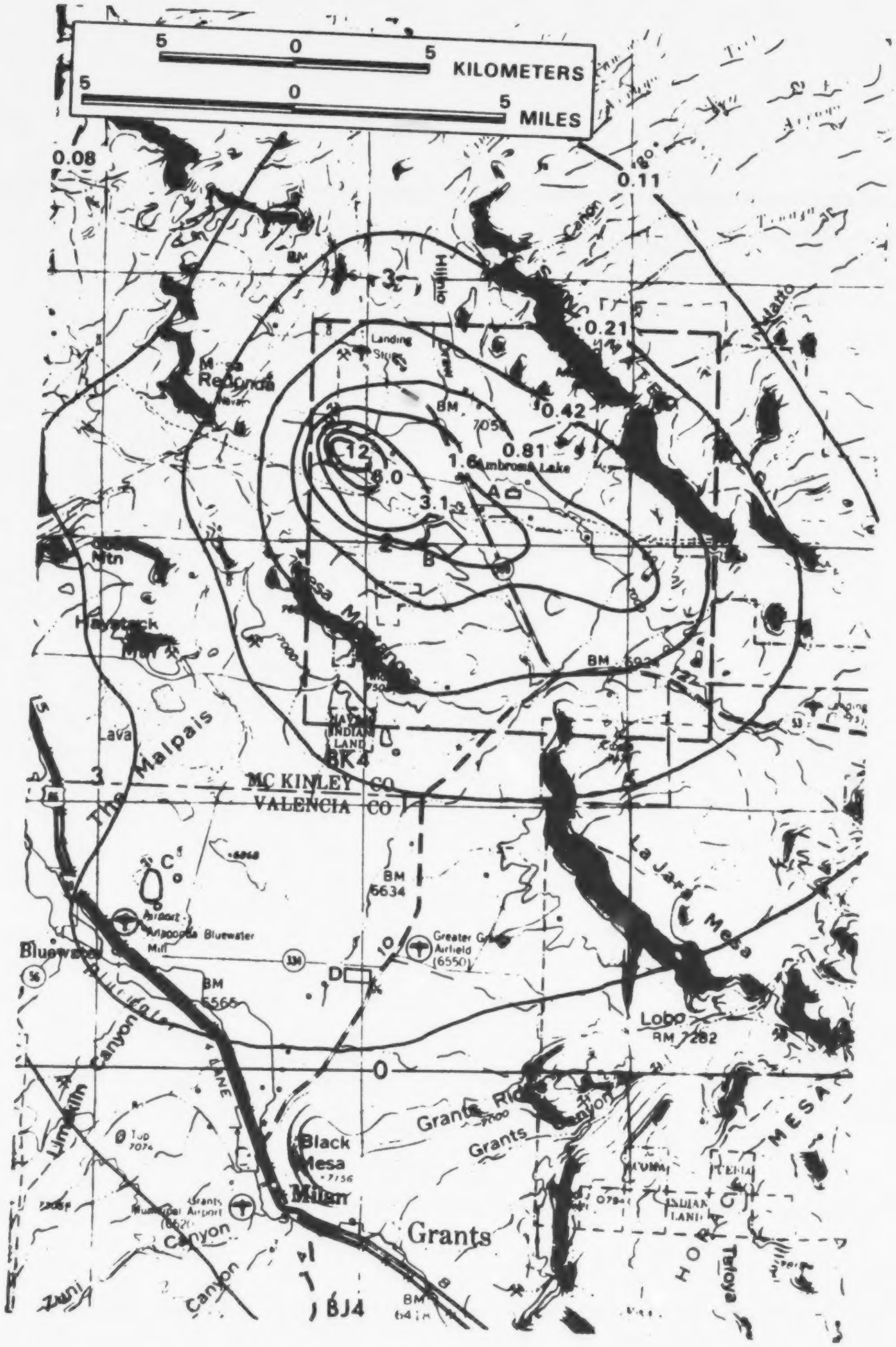

5 0 5 KILOMETERS
5 0 5 MILES
0.08
0.11
3
0.21
0.42
0.81
1.6
12
6.0
3.1
Ambrosia Lake
A
B
C
D
Mesa Redonda
Landing Strip
BM 7050
Haystack Mtn
Lava
The Malpais
MC KINLEY CO
VALENCIA CO
NAVAJO INDIAN LAND
BK4
BM 6634
Greater Grants Airfield (6550)
Airport
Anaconda Bluewater Mill
Bluewater
BM 6565
1
0
La Jara Mesa
Lobo
BM 7282
Grants Ridge
Grants Canyon
Black Mesa 7156
Milan
Grants Municipal Airport (6521)
Grants
Limekiln Canyon
Zuni Canyon
BJ4

Figure 5-6. Computed radon concentration map for region isopleths are in pCi/L.

5.8 Reduction of Exposures through Land Control

Rather than control radon emissions at the source, it may be more practical to limit the exposure to individuals near underground mines by controlling land near the vents to prevent people from living in houses in these areas. At the request of EPA, Battelle Northwest Laboratory conducted a field study in January and February 1983 to determine the population, type of ownership, and cost of land around 30 large uranium mines. These mines represented about 90 percent of the uranium production from underground mines at that time.

Table 5-11 shows the population data gathered from the Battelle study. An estimate was made of all residents within 5 km of the mine shaft by locating all the residences on a map. The average 1980 census figure of residents per home in each county was used to estimate the population. If mines were close together, populations were evenly distributed among the mines according to the distances from the mines.

Table 5-12 represents the percent distribution of land ownership around the 30 surveyed mines. County tax assessor's records were reviewed for all properties within a 5-km radius of each mine. The ownership of the land was determined and percentages, according to three types of ownership (private, mine, or government), are shown for each mine.

Table 5-13 summarizes the cost of the land around each mine. Since the land owned by the mine operator or a government agency can already be controlled, only costs to purchase private land were determined.

The Schwartzwalder mine near Denver, Colorado, is not included in the total cost of all surveyed mines shown in Table 5-13 because it is not a typical mine site. It is located near a large metropolitan area and the cost of the land is quite high since the land can be purchased or subdivided for mountain resort homes. The mine is also isolated in a mountainous region so that radon emissions would be confined in the immediate area of the mine and any land control which may be necessary would be relatively small.

The information in Tables 5-11 through 5-13 can be used to obtain a rough estimate of the cost to control land around underground uranium mines. The cost to control land within a 2-km radius of the mines surveyed is as follows:

Type of cost	Total cost (millions)	Yearly cost (millions)
Land cost (100% contingency with 10% yearly cost)	\$12.5	\$1.3
Structures (100% contingency with 30% amortization)	3.0	.9
Relocation of residents (\$5,000/ person with 30% amortization)	3.3	1.0
Purchase of Indian dwellings (\$20,000/ person--220 Indians, with 30% amortization)	4.4	1.3
Total yearly cost		4.5

The 10 percent yearly cost assumes that the land value does not change and thus is a nondepreciated asset. The 30 percent amortization figure assumes that the mine will operate for five years with an interest rate of 10 percent. A small amortization percentage is added to the interest rate for taxes.

Assuming that the 29 mines produced 90 percent of the underground mine yearly production of 8,600 tons of U_3O_8 for the industry (DOE82), the cost of land control per pound of U_3O_8 can be estimated as follows:

$$\text{cost/lb } U_3O_8 = \frac{\$4,500,000}{(.9)(8,600)(2,000)} = \$0.29/\text{lb } U_3O_8$$

If production costs for U_3O_8 are \$30/lb, the increased cost to the industry would be 1 percent of the cost of production.

Table 5-11. Population around selected underground uranium mines (B183)

Mine	State	Distance from mine (km)					
		0-1/2	0-1	0-2	0-3	0-4	0-5
Sunday	Colo.	0	0	0	0	0	0
King Solomon	Colo.	0	0	0	0	0	0
Velvet	Utah	0	0	0	0	0	0
Tony M	Utah	0	0	0	0	0	0
Hack Canyon	Arizona	1	1	1	1	1	1
Pidgeon	Arizona	0	0	0	0	0	0
Kabab North	Arizona	0	0	0	0	0	0
Dermo-Snyder	Colo/Utah	0	8	33	53	73	83
Wilson-Silverbell	Utah/Colo.	0	0	0	12	20	23
Lisbon	Utah	0	0	0	4	44	44
LaSal	Utah	0	0	53	101	194	194
Hecla	Utah	16	16	20	40	73	73
Big Eagle	Wyoming	0	0	0	0	0	3
Golden Eagle	Wyoming	0	0	0	9	12	12
Sheep Mtn.	Wyoming	0	0	0	0	0	12
Mt. Taylor	New Mexico	0	100	317	336	336	336
Old Church Rock	New Mexico	0	0	65	93	192	469
Church Rock-NE	New Mexico	12	31	51	53	53	93
Church Rock-1	New Mexico	12	30	51	54	54	93
Church Rock-East	New Mexico	0	0	19	19	30	78
Kerr-McGee Sec 30 East	New Mexico	3	3	8	8	12	13
Kerr-McGee Sec 30 West	New Mexico	0	0	0	0	0	0
Kerr-McGee Sec 19	New Mexico	0	0	0	0	0	0
Kerr-McGee Sec 35	New Mexico	0	0	0	0	0	0
Kerr-McGee Sec 36	New Mexico	0	0	0	0	0	0

Table 5-11. Population around selected underground uranium mines (B183) (Continued)

Mine	State	Distance from mine (km)					
		0-1/2	0-1	0-2	0-3	0-4	0-5
Homestake Sec 23	New Mexico	0	0	0	3	3	4
Homestake Sec 25	New Mexico	0	0	0	0	0	0
Nose Rock(a)	New Mexico	2	3	14	31	55	86
Mariano Lake(a)	New Mexico	3	5	21	47	83	130
Schwartz-walder(b)	Colorado	3	3	63	102	136	147
Totals		49	197	653	855	1235	1963

(a) Estimates for intermediate distances apportioned on area. These were on Indian land. Roads were impassable. Estimates out to 5 km were obtained from the Office of Environmental Health, USPHS Indian Hospital, Crown Point, New Mexico.

(b) The population around this mine is not included in the total because the location is not typical of the industry.

Table 5-12. Percent distribution of land ownership around selected underground uranium mines (B183)

Mine	Distance from mine (km)					
	0-1/2[a]	0-1	0-2	0-3	0-4	0-5
Sunday	0/0/100	0/0/100	0/0/100	3/1/97	8/1/91	10/1/89
King Solomon	0/0/100	0/2/98	0/5/95	0/3/97	0/3/97	0/3/97
Velvet	14/0/86	10/0/90	6/0/94	12/0/88	24/0/76	27/0/73
Tony M	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Hack Canyon	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Pidgeon	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Kanab North	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	1/0/99
Dermo-Snyder	84/0/16	87/0/13	84/0/16	89/0/11	85/0/15	81/0/19
Wilson-Silverbell	80/0/20	95/0/5	95/0/5	94/0/6	91/0/9	81/0/19
Lisbon	0/0/100	0/0/100	6/0/94	17/2/81	21/1/78	16/1/83
LaSal	8/0/92	25/0/75	34/0/66	41/0/59	34/0/66	26/0/74
Hecla	25/0/75	25/0/75	48/0/52	37/0/63	28/0/72	21/0/79
Big Eagle	0/100/0	0/88/12	0/80/20	0/8/92	0/5/95	1/3/96
Golden Eagle	60/20/20	89/7/4	85/3/2	94/1/5	91/1/8	90/1/9
Sheep Mtn.	30/45/25	18/42/40	5/28/69	2/18/80	4/11/85	12/8/80
Mt. Taylor	75/19/6	58/26/16	58/25/17	47/17/36	39/13/48	40/8/52
Old Church Rock	0/0/100	0/0/100	0/0/100	0/0/100	2/0/98	3/1/96
Church Rock NE	0/0/100	0/7/93	0/23/77	0/13/87	0/8/92	0/5/95
Church Rock #1	0/0/100	0/7/93	0/23/77	0/13/87	0/8/92	0/5/95
Church Rock East	0/0/100	0/7/93	0/6/94	3/4/93	5/2/93	3/1/96
Kerr-McGee Sec 30 East	11/89/0	4/91/5	2/70/28	4/78/18	10/79/11	13/77/10
Kerr-McGee Sec 30 West	11/89/0	24/76/0	17/72/11	16/69/15	22/66/12	27/57/16
Kerr-McGee Sec 19	0/100/0	23/77/0	46/39/15	45/39/16	32/37/31	29/38/33
Kerr-McGee Sec 35	0/100/0	0/85/15	8/59/33	14/55/31	10/57/33	14/52/34
Kerr-McGee Sec 36	5/42/53	14/22/64	27/14/59	36/8/56	36/5/59	39/3/58

See footnotes at end of table.

Table 5-12. Percent distribution of land ownership around selected underground uranium mines (B183) (Continued)

Mine	Distance from mine (km)					
	0-1/2[(a)]	0-1	0-2	0-3	0-4	0-5
Homestake Sec 23	74/0/26	68/0/32	61/6/33	50/18/32	47/17/36	53/12/35
Homestake Sec 25	100/0/0	85/0/15	59/0/41	58/1/41	50/2/48	43/10/47
Nose Rock	0/50/50	0/50/50	0/45/55	0/41/59	0/38/62	0/35/65
Mariano Lake	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100	0/0/100
Schwartz walder[(b)]	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0	100/0/0
Average	20/22/58	22/20/58	22/17/61	23/13/64	22/12/66	22/11/67

(a) The first figure in the column represents the percent of private land, the second is land owned by the mine owner, and the third shows the percentage of land owned by a government agency. For example, in the case of the Sunday mine (at 0-1/2 km), 100 percent is owned by the government.

(b) The land ownership percentage for the Schwartzwalder mine was not included in the average for all the mines since the location is not typical of the industry.

Table 5-13. Estimated value of private land around selected underground uranium mines(a) (B183)
(In thousands)

Mine	Distance from mine (km)					
	0-1/2	0-1	0-2	0-3	0-4	0-5
Sunday	NA	NA	NA	48.0	208.0	384.0
King Solomon	NA	NA	NA	NA	NA	NA
Velvet	5.5	16.0	36.0	172.8	603.2	1,048.0
Tony M	NA	NA	NA	NA	NA	NA
Hack Canyon	NA	NA	NA	NA	NA	NA
Pidgeon	NA	NA	NA	NA	NA	NA
Kanab North	NA	NA	NA	NA	NA	(b)
Dermo-Snyder	79.7	260.4	922.6	1,852.1	3,028.9	4,432.8
Wilson-Silverbell	39.1	186.4	535.8	1,667.2	2,861.6	3,968.7
Lisbon	NA	NA	50.0	306.0	810.5	810.5
LaSal	4.0	228.4	920.9	1,427.8	2,484.5	2,534.5
Hecla	36.8	147.3	380.0	691.0	965.9	1,000.5
Big Eagle	NA	NA	NA	NA	NA	NA
Golden Eagle	35.4	209.0	796.2	2,121.0	3,584.0	5,435.0
Sheep Mtn.	18.0	42.3	42.3	42.3	150.0	898.0
Mt. Taylor	39.6	225.1	890.7	1,211.8	1,604.9	2,296.3
Old Church Rock	NA	NA	NA	NA	543.3	1,443.1
Church Rock NE	NA	NA	NA	NA	NA	NA
Church Rock-1	NA	NA	NA	NA	NA	NA
Church Rock-East	NA	NA	NA	122.2	355.6	355.6
Kerr-McGee Sec 30 East	35.0	35.0	35.0	53.5	147.6	240.0
Kerr-McGee Sec 30 West	31.1	132.2	147.8	157.9	194.8	235.1
Kerr-McGee Sec 19	NA	194.4	844.8	1,229.4	1,405.1	1,532.8
Kerr-McGee Sec 35	NA	NA	37.0	137.8	168.0	336.0
Kerr-McGee Sec 36	3.4	23.5	124.3	336.0	588.0	977.8

See footnotes at end of table.

Table 5-13. Estimated value of private land around selected underground uranium mines(a) (B183) (Continued)
(In thousands)

Mine	Distance from mine (km)					
	0-1/2	0-1	0-2	0-3	0-4	0-5
Homestake Sec 23	217.8	528.0	994.1	1,158.7	1,485.2	2,361.8
Homestake Sec 25	295.6	622.2	987.8	1,478.0	1,632.2	1,645.6
Norse Rock	NA	NA	NA	NA	NA	NA
Mariano Lake	NA	NA	NA	NA	NA	NA
Schwartz walder(c)	880.0	3,400.0	15,200.0	33,600.0	58,400.0	89,200.0
Totals	841.0	2,850.2	7,745.2	14,213.4	22,821.3	31,937.1

(a) Includes cost of land and structures.

(b) About 100 acres of patented mining claims.

(c) The costs for this mine were not included in the total costs because the location and cost of land is not typical of the industry.

NA Not assessed; all land owned by either the mine owner or the government.

REFERENCES

Bl83 Written communication between C. Bloomster of Battelle-Pacific Northwest Laboratory and J. Silhanek, EPA, January and February 1983.

Br81 Brown S. H and Smith R. C., A Model for Determining the Overall Radon Release Rate and Annual Source Term for a Commerical In-Situ Leach Uranium Facility, Proceedings of International Conference on Radiation Hazards in Mining: Control Measurement, and Medical Aspects, Colorado School of Mines, Golden, Colorado, October 1981.

DOE82 Department of Energy, Statistical Data of the Uranium Industry, GJO-100(82), Grand Junction, Colorado, January 1982.

Dra80 Droppo, J. G., et al., An Environmental Study of Active and Inactive Uranium Mines and Their Effluents, Part I, Task 3, Pacific Northwest Laboratory, PNL-3069, Part I, August 1980.

Drb81 Droppo, J. G. and Glissmeyer, J. A., An Assessment of the Radon Concentrations in Air Caused by Emissions from Multiple Sources in a Uranium Mining and Milling Region. A Case Study of the Ambrosia Lake Region of New Mexico, Pacific Northwest Laboratory, PNL-4033, December 1981.

EPA79 Environmental Protection Agency, Radionuclide Impact Caused by Emissions of Radionuclides into Air in the United States, EPA 520/7-79-006, EPA, Office of Radiation Programs, Washington, D.C., August 1979.

EPA82 Environmental Protection Agency, Draft Environmental Impact Statement for Remedial Action Standards for Active Uranium Processing Sites, EPA, Office of Radiation Programs, Washington, D.C., 1982.

EPA83 Environmental Protection Agency, Potential Health and Environmental Hazards of Uranium Mines Wastes (Draft), Office of Radiation Programs, Washington, D.C., March 1983.

Fr81 Franklin J. C., Control of Radiation Hazards in Underground Mines, Bureau of Mines, Proceedings of International Conference on Radiation Hazards in Mining: Control Measurement, and Medical Aspects, Colorado School of Mines, Golden, Colorado, October 1981.

REFERENCES--continued

Ja80 Jackson P. O., et al., An Investigation of Radon-222 Emissions from Underground Uranium Mines--Progress Report 2, Pacific Northwest Laboratory, Richland, Washington, February 1980.

Ko80 Kown B. T., et al., Technical Assessment of Radon-222 Control Technology for Underground Uranium Mines, EPA Contact No. 68-02-2616, ORP/TAD-80-7, EPA, Office of Radiation Programs, Washington, D.C., April 1980.

Chapter 6: PHOSPHATE INDUSTRY FACILITIES

6.1 Phosphate Rock Processing Plants

6.1.1 General Description

Phosphate rock is the starting material for the production of all phosphate products. Mining of phosphate rock is the fifth largest mining industry in the United States in terms of quantity of material mined (Da68). Phosphate rock mines of significant commercial importance are located in Florida, North Carolina, Tennessee, Idaho, Wyoming, Utah, and Montana (Figure 6.1-1).

The U.S. production of phosphate rock was estimated to be 57.9 million metric tons in 1978 with production increasing an average of about 5 percent per year (EPA79). The industry consists of 20 firms which are currently mining phosphate rock at 31 locations. Another five mines are expected to be operational by 1983, and four others have been planned with indefinite start-up dates. Most firms have mining operations and rock processing plants at the same location, while a few companies mine in several areas and ship the rock to a central processing plant. Table 6.1-1 shows the phosphate rock producing companies, plant locations, 1977 production, and percent of U.S. market.

The southeastern U.S. is the center of the domestic phosphate rock industry, with Florida, North Carolina, and Tennessee having over 90 percent of the domestic rock capacity. Florida, with approximately 78 percent of 1978 domestic capacity, dominates the U.S. industry and is the world's largest phosphate rock producing area. Most of these plants are located around Polk and Hillsborough counties in Central Florida, with expansion taking place in Hardee and Manatee counties. Hamilton County, located in North Florida, is another phosphate rock producing area.

Tennessee's phosphate rock industry, located in the middle of the State, has declined in importance over the last several years and is now the least important rock producing area in the country. The Tennessee Valley Authority and two private corporations have discontinued mining in Tennessee, and no new plant expansion is planned.

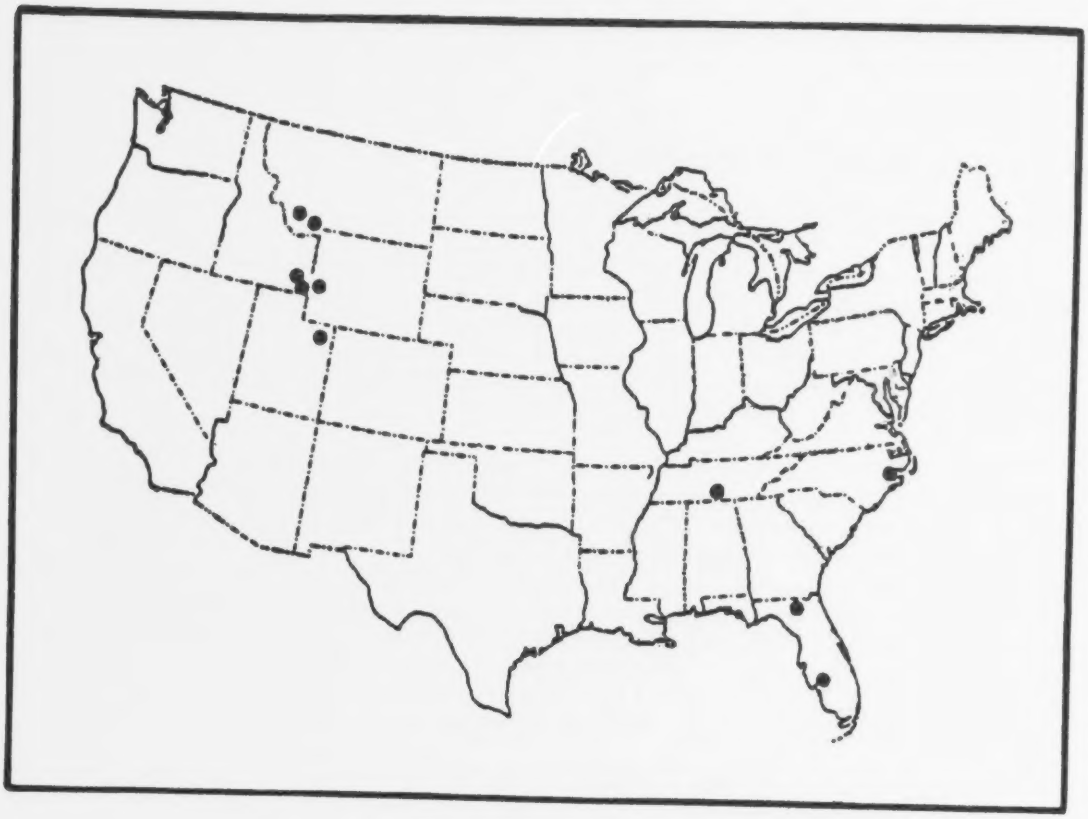


Figure 6.1-1. Geographical location of phosphate rock operations.

Table 6.1-1. Phosphate rock producers and capabilities (EPA79)

Company and location	1977 production (Metric tons) (10^3)	Percent of total
International Minerals and Chemicals Bonnie, Florida Kingsford, Florida Noralyn, Florida	11,340	20.5
Agrico Chemical Co. (Williams) Pierce, Florida Ft. Green, Florida	8,618	15.6
Occidental Agricultural Chemicals White Springs, Florida	2,722	4.9
Mobile Chemical Nichols, Florida Fort Meade, Florida	4,264	7.7
Brewster Phosphate Brewster, Florida Bradley, Florida	3,175	5.7
U.S. Steel-Agri-Chem, Inc. Ft. Meade, Florida	1,814	3.3
Gardinier Ft. Meade, Florida	1,966	3.6
Swift Chemical Bartow, Florida	2,903	5.3
W.R. Grace & Company Hookers Pr., Florida Bonnie Lake, Florida Manatte Co., Florida	4,808	8.7
Borden Chemical Company Teneroc, Florida Big Four, Florida	907	1.6
T-A Minerals Polk City, Florida	454	0.8

Table 6.1-1. Phosphate rock producers and capabilities (EPA79) --continued

Company and location	1977 production (Metric tons) (10^3)	Percent of total
Beker Industries Dry Valley, Idaho	1,089	2.0
J.R. Simplot Ft. Hall, Idaho	1,814	3.3
Cominco-American Garrison, Montana	249	0.5
George Relyea Garrison, Montana	91	0.2
Texasgulf Aurora, North Carolina	4,536	8.2
Stauffer Chemical Company Mt. Pleasant, Tennessee Vernal, Utah Wocley Valley, Utah	1,950	3.5
Hooker Chemical Company Columbia, Tennessee	454	0.8
Presnell Phosphate Columbia, Tennessee	454	0.8
Monsanto Industrial Chemical Co. Columbia, Tennessee Henry, Idaho	1,814	3.3

Summary by Region

Location	Percent of total U.S.
Florida	78.3
North Carolina	7.8
Tennessee	4.1
Western States	9.8

North Carolina possesses a rich phosphate rock deposit in Beaufort County along the Pamlico River. Texasgulf, the only company currently exploiting this resource, recently expanded plant capacity by 43 percent and has plans for further expansion. Another company has announced plans for a large operation in Washington, North Carolina.

The western U.S. phosphate rock industry is located in eastern Idaho, northern Utah, western Wyoming, and southern Montana. This area accounts for almost six million metric tons per year of the U.S. capacity, or about 10 percent. Six companies currently operate seven mines and six processing plants.

The U.S. industry is relatively concentrated as the 10 largest producers control about 84 percent of the capacity. The two largest companies control over 34 percent. In the Florida region, two firms have nearly 44 percent of the State's capacity, while the five largest companies control over 70 percent (EPA79).

The principal ingredient of the phosphate rock that is of economic interest is tricalcium phosphate, $Ca_3(PO_4)_2$. However, phosphate rock also contains appreciable quantities of uranium and its decay products. The uranium concentration of phosphate rock ranges from 20 to 200 ppm which is 10 to 100 times higher than the uranium concentration in natural material rocks and soils (2 ppm). The radionuclides of significance which are present in phosphate rock are: uranium-238, uranium-234, thorium-230, radium-226, radon-222, lead-210, and polonium-210. Because phosphate rock contains elevated concentrations of these radionuclides, handling and processing the rock can release radionuclides into the air either as dust particles, or in the case of radon-222, as a gas.

6.1.2 Process Description

After phosphate rock has been mined and beneficiated, it is usually dried and ground to a uniform particle size to facilitate processing. The drying and grinding operations produce significant quantities of particulate material (phosphate rock dust).

Phosphate rock is dried in direct-fired rotary or fluidized-bed dryers. The rock contains 10-15 percent moisture as it is fed to the dryer and is discharged when the moisture content reaches 1-3 percent. Dryer capacities range from 5 to 350 tons per hour (tph), with 200 tph a representative average.

Crushing and grinding are widely employed in the processing of phosphate rock. Operations range in scope from jaw crushers which reduce 12-inch hard rock to fine pulverizing mills which produce a product the consistency of talcum powder. Crushing is employed in some locations in the western field; however, these operations are used for less than 12 percent of the rock mined in the U.S. Fine pulverizing mills or grinders are used by all manufacturers to produce fertilizer. Roller or ball mills are normally used to process from 15 to 260 tph.

Some phosphate rock must be calcined before it can be processed. The need for calcining is determined primarily by the quantity of organic materials in the beneficiated rock. Since Florida rock is relatively free of organics, it usually is not calcined. Most calcining is done in fluidized-bed units, but rotary calciners are also used. The rock is heated to 1400°-1600° F in the calciner to remove unwanted hydrocarbons. Calciners range in capacity from 20 to 70 tph; a representative average is about 50 tph (EPA79).

6.1.3 Control Technology (TRW82a)

At phosphate rock plants, the normal sequence of operation is: mining, beneficiation, conveying of wet rock to and from storage, drying or calcining, conveying and storage of dry rock, grinding, and conveying and storage of ground rock.

Over 98 percent of the phosphate rock produced in the United States is mined from ground where the moisture content is high enough to preclude particulate emissions during extraction of the ore. In the relatively small amount of mining performed in areas where ground moisture content is not sufficient to prevent emissions, such as the hard rock areas of Utah and Wyoming, some particulates are generated during blasting and handling of the overburden and ore body. These emissions are minimized by wetting the active mining area with water from tank trucks.

Beneficiation is performed in a water slurry. Since the rock is wet, it does not become airborne and presents no particulate problem. Mined rock is normally moved by conveyor belts. Some are open, others closed for weather protection. In all except the relatively small plants in the hard rock areas of Utah and Wyoming, the high moisture content of the rock prevents emission of particulates. Weather-protected conveyors also offer some emission control in arid or windy locations.

Particulates from conveying and storage of ground rock are due primarily to fugitive emissions. Conveying and storage of ground rock usually takes place in totally enclosed systems, where proper maintenance will minimize fugitive losses.

Particulate emissions from dryers, calciners, and grinders could be reduced by applying particulate control equipment to "non-fugitive" emission sources.

Controlled emission levels from dryers and calciners can vary considerably from unit to unit, even with the same control device, due primarily to the effects of feed rock characteristics. Industrial representatives have indicated that feed rock characteristics greatly outweigh the effects of dryer or calciner unit types. Several feed rock characteristics can affect the emission levels and particle size distribution of the exhaust gas streams. Surface properties affect emission levels; rough or pitted surfaces can have greater clay adhesion, resulting in higher emission levels and smaller average particle size.

During beneficiation, the least-washed rock will have more fines, higher emission levels, and smaller average particle size. The residence time during which the rock is dried or calcined may also affect emission levels. Although increasing the residence time may lower particulate concentration per volume of exhaust gas, the total weight of particulate emission per weight of feed rock will increase. Other feed rock characteristics can also cause fluctuations in the particulate emission levels.

Coarse pebble rock from Florida is beneficiated the least and has the longest residence time in the dryer of all Eastern rock. Along with other properties, including hardness and clay adhesion, these properties cause coarse pebble rock to produce the most adverse, or worst-case, control levels for Eastern operations. However, unbeneficiated Western rock has a slightly smaller average particle size than Eastern rock and represents the most adverse of all feed rock control situations.

Dryer and Calciner Controls

Phosphate rock calciners and dryers have similar emission characteristics. Scrubbers are the most common control device used in the operation of phosphate rock dryers and calciners. Probably the most important design parameters for scrubbers are the amount of scrubber water used per unit volume of gas treated (liquid-to-gas ratio) and the intimacy of contact between the liquid and gas phases. The latter parameter is generally related to the pressure drop across the scrubber. Because of the similarities in emissions from dryers and calciners, scrubbers can attain similar reduction efficiencies; up to greater than 99.0 percent for high-energy venturi scrubbers.

Electrostatic precipitators (ESP) can be an economical control technique. Plate (electrode) voltage and the ratio of plate area to the volume of gas to be treated are the most important design parameters of an ESP. Particle resistivity and the ease of cleaning collected dust from the plates also affect ESP performance. Electrostatic precipitation is sometimes an economically attractive control technique in cases where fine dust particles predominate. Removing fine particles with a venturi scrubber requires relatively large power inputs (high pressure drops) to achieve the necessary efficiency. If power cost savings effected by the ESP exceed the increased capital charges, this system can be more economical than the venturi scrubber.

Two phosphate rock dryers now use electrostatic precipitators. One has a conventional dry ESP to control emissions from two rotary dryers. The precipitator was designed for 95 percent efficiency, but typically operates at 93 percent. The other uses a wet ESP to control emissions from two dryers operated in parallel, one a rotary design and the other a fluid bed. The ESP was designed for an efficiency of 90 percent, but is probably operating at a higher efficiency because the gas flow rate is about 60 percent of design capacity. With variation in plate voltage and plate area, ESP's can be designed to achieve reduction efficiencies up to greater than 99 percent. A calciner at one existing operation has a two-stage, dry ESP which operates with an indicated overall efficiency of 99.8 percent.

No fabric filters are known to be in use for phosphate rock dryer and calciner emission control. Many industry members believe that moisture condensation would be a major problem because water droplets could mix with the clay-like dust mat formed on the fabric media and cause a mud cake. Were this condition to occur, it would "blind" the bags. Furthermore, since the dust usually has no economical value, dry recovery for reprocessing is not an attractive incentive to operators. High exhaust gas temperatures associated with calciners are also commonly cited as a major difficulty expected with this type control device. However, manufacturers of these devices believe fabric filters can be effective for this application. They state that successful operation of fabric filters are common in more difficult operations, such as asphalt plants, cement plants, fertilizer dryers, and the clay industry. Under proper operating conditions, fabric filters generally exceed 99 percent efficiency.

Grinder Controls

Dried and calcined rock is ground before it is used for the manufacture of fertilizers. The grinding or milling circuit operates under slightly negative pressure to prevent the escape of gases containing ground rock dust. The system is not airtight; hence, the air that is drawn into the system must be vented. This vent stream usually discharges through a fabric filter or, sometimes, a wet scrubber. Electrostatic precipitators are not used for this operation at existing facilities.

Fabric filters are normally used to control emissions from grinders, probably because the dust collected by a fabric filter can be added directly to the product and thereby increase yields. Also, the low moisture content of 5 percent or less and low temperatures make fabric filtration technically and economically feasible. A well maintained and operated baghouse routinely controls particulate emissions to levels greater than 99 percent.

In some plants higher moisture content of the ground rock dust causes difficulty. At these plants, wet collectors are usually chosen for control. These devices can typically control emissions from 90 to

98 percent depending on the pressure drop. There has been a recent move toward wet grinding of rock for the manufacture of wet-process phosphoric acid (WPPA). The rock is ground in a water slurry, then added to the WPPA reaction tanks without drying. This offers the advantages of lower fuel costs and ability to meet more stringent particulate emission regulations. Two companies are now using the wet grinding process.

6.1.4 Radionuclide Emission Measurements

Phosphate rock dust is a source of particulate radioactivity in the atmosphere because the dust particles have approximately the same specific activity (pCi/g) as in the phosphate rock. Very limited data are available for actual field measurements of radioactivity in dryer/grinder air emissions. Measurements made by EPA (EPA78) are summarized in Table 6.1-2.

Table 6.1-2. Radionuclide stack emissions measured at phosphate rock dryers (EPA78)

Parameter	Dryer 1	Dryers 3 and 4
Total particulates (g/y)	2.2E+7	5.0E+7
Operating time (hr/y)	4114	4338
Stack emissions (Ci/y)		
Uranium-234	7.0E-4	2.6E-3
Uranium-235	3.0E-5	2.4E-4
Uranium-238	6.6E-4	2.7E-3
Thorium-227	5.0E-5	2.0E-4
Thorium-228	1.4E-4	2.3E-4
Thorium-230	9.7E-5	2.5E-3
Thorium-232	3.0E-5	8.0E-5
Radium-226	9.3E-4	2.9E-3

In estimating the radionuclide emissions from phosphate rock processing plants in the following sections, the emissions for the calciner plants are assumed to be similar to those of dryer plants (i.e., the radionuclide concentration of the particulates emitted to air is similar to the concentration in the phosphate rock processed). However, unlike dryer plants, no measurements of radionuclide emissions from calciner plants have been made. Therefore, some uncertainty exists as to the validity of the above assumption with respect to polonium-210 emissions. Because calciners operate at higher temperatures than dryers, polonium-210 may be volatized from the phosphate rock and emitted in larger quantities than the other radionuclides in the uranium-238 decay series. In this case, our assumption that calciner plant emissions are similar to dryer plant emissions would underestimate the polonium-210 emissions. EPA is planning to conduct radionuclide emission studies at calciner plants to resolve this uncertainty.

6.1.5 Reference Plant

Table 6.1-3 describes the parameters of a reference phosphate rock drying and grinding plant which are used to estimate the radioactive emissions to the atmosphere and the resulting health impacts. The radioactive emissions from the reference plant are listed in Table 6.1-4. These emissions are representative of dryers with low energy scrubbers which releases 130 grams of particulates per MT of rock processed and of grinders with medium energy scrubbers which release 25 grams of particulates per MT of rock processed.

Table 6.1-3. Reference phosphate rock drying and grinding plant

Parameter	Dryers	Grinders
Number of units[a]	3	4
Phosphate rock processing rate (MT/y)	2.7E+6	1.2E+6
Operating factor (hr/y)	6570	6460
Uranium-238 content of phosphate rock (pCi/g)[b]	40	40
Stack parameters		
Height (meters)	20	20
Diameter (meters)	2	2
Exit gas velocity (m/s)	10	10
Exit gas temperature (°C)	60°	60°
Type of control system	Low energy scrubber	Medium energy scrubber
Particulate emission rate (g/MT)	130 (0.26)[c]	25 (0.05)[c]

[a] Dryer units process 145 MT/hr; grinder units process 45 MT/hr.

[b] Uranium-238 is assumed to be in equilibrium with its daughter products.

[c] Values in lb/ton.

Table 6.1-4. Radionuclide emissions from the reference phosphate rock drying and grinding plant

Radionuclide	Emissions (Ci/y)	
	Dryers	Grinders
Uranium-238	1.4E-2	1.0E-3
Uranium-234	1.4E-2	1.0E-3
Thorium-230	1.4E-2	1.0E-3
Radium-226	1.4E-2	1.0E-3
Lead-210	1.4E-2	1.0E-3
Polonium-210	1.4E-2	1.0E-3

6.1.6 Health Impact Assessment of Reference Plant

The estimated annual radiation doses from radionuclide emissions from the reference phosphate rock drying and grinding plant are listed in Table 6.1-5. These estimates are for a model site in central Florida with a regional population of 1.4E+6. The maximum individual is located 750 meters from the plant.

Table 6.1-6 presents estimates of the maximum individual lifetime risk and the number of fatal cancers per year of operation from these doses.

The lifetime risk to the maximum individual is estimated to be about 3E-5 and the number of fatal cancers per year of operation is estimated to be 3E-3. These risks result primarily from doses to the lung from inhalation of radioactive particulates released from drying operations.

6.1.7 Alternative Control Technology

The annualized costs and risk reductions achieved by adding alternative controls to the reference phosphate rock drying and grinding plant are shown in Table 6.1-7. Two alternative levels of control are evaluated for dryers:

1. Reduction of the particulate emissions to 50 g/MT through the use of medium energy venturi scrubbers or ESP's.

2. Reduction of the particulate emissions to 30 g/MT (level of New Source Performance Standards--NSPS) through the use of high energy venturi scrubbers or high energy ESP's.

For grinders, only one alternative level of control is evaluated; the reduction of the particulate emissions to 6 g/MT (level of NSPS) through the use of fabric filters or high energy venturi scrubbers.

Table 6.1-5. Annual radiation dose from radioactive particulate emissions from the reference phosphate rock drying and grinding plant

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	7.2	6.0E+1
Endosteal	1.5E+1	1.1E+2
Red marrow	1.3	9.2
Kidney	1.0	6.8
Weighted Sum	2.7	2.2E+1

Table 6.1-6. Fatal cancer risks due to radioactive emissions from the reference phosphate rock drying and grinding plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Dryers	3E-5	3E-3
Grinders	2E-6	2E-4
Total	3E-5	3E-3

Table 6.1-7. Annualized cost and risk reductions of alternative controls for the reference phosphate rock drying and grinding plant(a)

Process	Control option(b)	Emission rate (g/MT)	Total annual cost(c) ($1,000)	Fatal cancer risks		Cost/fatal cancer avoided (in millions)
				Individual lifetime risk	Population (cancers/y of operation)	
Dryers(b)	Existing	130	-	3E-5	3E-3	-
	B-1	50	861	1E-5	1E-3	430
	B-2	50	1770	1E-5	1E-3	885
	A-1	30(d)	1000	7E-6	7E-4	435
	A-2	30	2320	7E-6	7E-4	1000
Grinders	Existing	25	-	2E-6	2E-4	-
	A-1	6(d)	124	5E-7	5E-5	825
	A-2	6	4	5E-7	5E-5	27

(a) TRW82.

(b) For dryers:
B-1 = venturi scrubber (15" W.G.)
B-2 = ESP
A-1 = venturi scrubber (25" W.G.)
A-2 = high energy ESP

For grinders:
A-1 = venturi scrubber (16" W.G.)
A-2 = fabric filter

(c) Incremental cost for installing and operating alternative control system (i.e., cost above the existing costs).

(d) Level of control for New Source Performance Standards.

6.1.8 Total Health Impact of Phosphate Rock Processing Plants

Phosphate rock processing plants (dryers, calciners, and grinders) release about 5500 MT of particulate matter per year with the existing level of control (TRW82). This particulate matter contains about 220 mCi of uranium-238 and each of its daughter products. These emissions are estimated to cause about 5E-2 fatal cancers per year of operation. This estimate was derived from a ratio of the amount particulate matter released from all plants to the amount released from the reference facility:

$$\text{Number of fatal cancers per year from all plants} = \frac{5500 \text{ MT PM/yr}}{380 \text{ MT PM/yr}} \times .0032 \text{ HE/yr (reference facility)}$$

$$= 0.046$$

6.1.9 Costs and Risk Reductions for Retrofitting Existing Plants

The industry incremental annualized costs to retrofit existing phosphate dryer, calciner and grinding units are shown in Table 6.1-8.

To retrofit existing dryers with medium energy venturi scrubbers would cost an additional $6 million per year and would avoid 0.007 fatal cancers/year, or a cost of $785 million per fatal cancer avoided. Retrofitting to the NSPS level (Control Option A) would cost an additional $12 million per year and avoid 0.02 fatal cancers per year, or a cost of $610 million per fatal cancer avoided.

To retrofit existing calciners with medium energy venturi scrubbers would cost about an additional $3 million per year and would avoid 0.002 fatal cancers per year, or a cost of $1.4 billion per fatal cancer avoided. Retrofitting to the NSPS level (Control Option A) would cost an additional $12 million per year and would avoid 0.006 fatal cancers per year, or a cost of $2 billion per fatal cancer avoided.

Retrofitting the existing grinders to the NSPS levels (Control Option A) would cost an additional $340,000 per year and avoid 0.002 fatal cancers per year, or a cost of $170 million per fatal cancer avoided.

Table 6.1-8. Industry annualized costs and risk reductions for retrofitting existing phosphate rock dryers, calciners and grinders[a]

Process unit	Control option[b]	Total cost[c] (millions)	Fatal cancers avoided/y	Cost/fatal cancer avoided (in millions)
Dryers	B	5.5	7E-3	785
	A	12.2	2E-2	610
Calciners	B	2.7	2E-3	1350
	A	12.3	6E-3	2000
Grinders	A	0.34	2E-3	170

[a] TRW82.

[b] For dryers and calciners Option B is a venturi scrubber (15" W.G.) and Option A is a venturi scrubber (25" W.G.). For grinders, Option A is a fabric filter.

[c] Incremental cost for installing and operating alternative control system (i.e., costs above existing costs).

REFERENCES

Da68 Dames and Moore, Airborne Radioactive Emission Control Technology, Report on EPA Contract 68-01-4992, White Plains, New York, Unpublished.

EPA78 Environmental Protection Agency, Radiation Dose Estimates due to Air Particulate Emissions from Selected Phosphate Industry Operations, ORP/EERF-78-1, Office of Radiation Programs, Montgomery, Alabama, 1978.

EPA79 Environmental Protection Agency, Phosphate Rock Plants, Background Information for Proposed Standards, EPA-450/3-79-017, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina, 1979.

TRW82 Particulate Emissions and Control Costs of Radionuclide Sources in Phosphate Rock Processing Plants. A report prepared by Butch Smith (TRW) for Office of Radiation Programs, December 1982.

6.2 Wet Process Fertilizer Plants

6.2.1 General Description

Most phosphate rock produced in the United States is used for the production of high-analysis agricultural fertilizers. In 1976, 50 million metric tons of phosphate rock were used to produce 9 million metric tons of phosphoric acid, the starting material for ammonium phosphate and triple superphosphate fertilizers (EPA79).

6.2.2 Process Description

Wet process phosphoric acid is produced by mixing ground phosphate rock with 93 percent sulfuric acid and water. In the process gypsum (calcium sulfate) is produced as a byproduct. The simplified overall reaction is represented by:

$$3Ca_3(PO_4)_2 + 9H_2SO_4 + 18H_2O = 6H_3PO_4 + 9CaSO_4 \cdot 2H_2O \qquad (1)$$

Phosphate rock is not the pure compound indicated above, but a fluoroappitite material containing minor quantities of flourine, iron, aluminum, silica and uranium. Following the reaction in the digester, the mixture of phosphoric acid and gypsum is pumped to a filter which mechanically separates the particulate gypsum from the phosphoric acid (approximately 30 percent phosphorus pentoxide concentration). An enormous amount of the byproduct gypsum is produced--each metric ton of phosphorus pentoxide, as phosphoric acid, produces approximately 5 metric tons of gypsum. Normally, the gypsum is sluiced with process water from the plant to the disposal area. The phosphoric acid separated from the gypsum is collected for further processing (EPA79).

The phosphoric acid is then used to produce several different grades of agricultural fertilizers. Triple superphosphate (TSP) fertilizer is made using ground phosphate rock and phosphoric acid as in the following equation:

$$Ca_3(PO_4)_2 + 4H_3PO_4 + 3H_2O = 3Ca(H_2PO_4)_2 \cdot 2H_2O \qquad (2)$$

Ammonium phosphate fertilizer is made using ammonia and wet process phosphoric acid. Monoammonium phosphate (MAP) and diammonium phosphate (DAP) are produced as in the following equations:

$$H_3PO_4 + NH_3 = NH_4H_2PO_4 \qquad \text{MAP} \qquad (3)$$

$$H_3PO_4 + 2NH_3 = (NH_4)_2HPO_4 \qquad \text{DAP} \qquad (4)$$

The steps involved in the wet process production of agricultural fertilizers are summarized in Table 6.2-1. The major sources of radionuclide emission in particulate dust results in the product drying and handling areas.

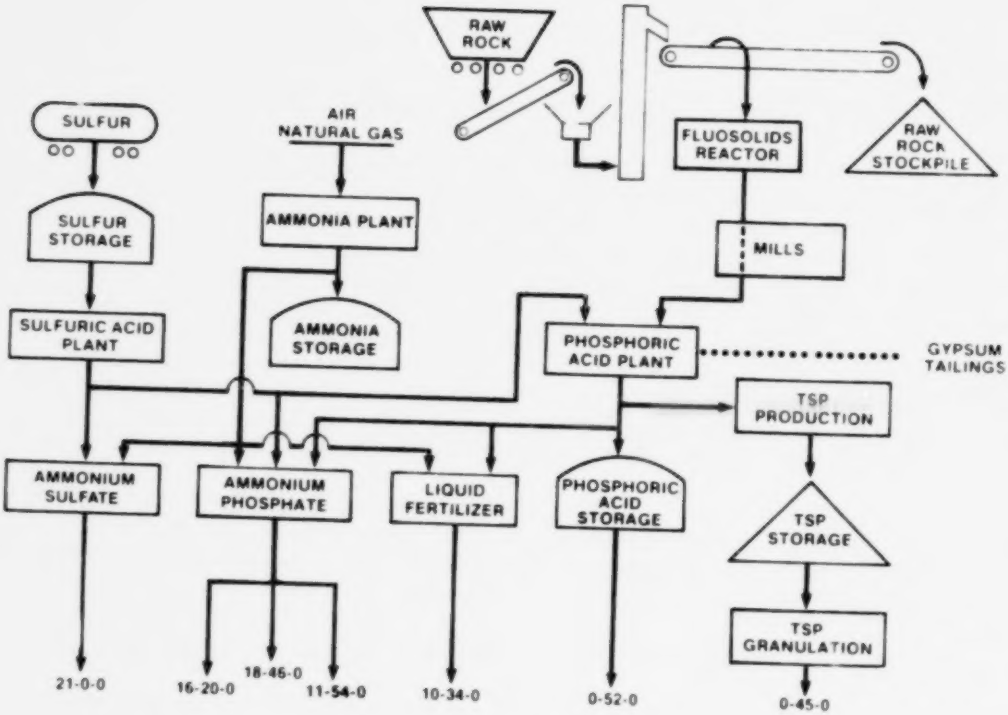

RAW ROCK
SULFUR
AIR
NATURAL GAS
FLUOSOLIDS REACTOR
RAW ROCK STOCKPILE
SULFUR STORAGE
AMMONIA PLANT
MILLS
SULFURIC ACID PLANT
AMMONIA STORAGE
PHOSPHORIC ACID PLANT
GYPSUM TAILINGS
TSP PRODUCTION
AMMONIUM SULFATE
AMMONIUM PHOSPHATE
LIQUID FERTILIZER
PHOSPHORIC ACID STORAGE
TSP STORAGE
TSP GRANULATION
21-0-0
16-20-0
18-46-0
11-54-0
10-34-0
0-52-0
0-45-0

Figure 6.2-1. Flow diagram of the wet process (EPA79).

6.2.3 Control Technology (TRW82)

Production processes for diammonium phosphate (DAP) and granular triple superphosphate (GTSP) are similar. The same process equipment in certain plants is used to produce both DAP and GTSP on an alternating basis; therefore, the control equipment for DAP and GTSP processes is similar. The particulate matter emission points within the DAP and GTSP production processes are as follows:

- reactor/granulator exhaust(s);
- dryer exhaust;
- cooler exhaust where appropriate; and
- screens, mills, and materials handling ventilation system(s) and exhaust(s).

Additional particulate matter (PM) emission sources exist in the ground rock raw materials handling (GTSP only) and final product handling systems (DAP and GTSP). These sources, however, are mostly "fugitive" sources and not process sources.

The DAP and GTSP processes currently in operation employ a variety of wet scrubbing systems on each of the major process exhaust streams. In most instances, scrubbers are installed in series. Generally, individual scrubbing systems are designated as "primary," "secondary," etc., referring to their order in the series of control devices.

Scrubbing systems have not been installed to control particulate matter; rather, process economic considerations and flouride emissions control have prompted installation of the scrubbing systems. In the DAP process, the primary scrubber uses phosphoric acid as a scrubbing solution to recover ammonia raw materials that otherwise would be lost. Without ammonia recovery, the cost of manufacturing DAP is not competitive. Secondary scrubbing systems have been installed by and large to control flouride emissions, to ensure worker safety, and to meet environmental regulations. Secondary scrubbing systems generally use recirculated process water (pond water) to enhance flouride removal. Some plants operate tertiary scrubbers for the same reasons. The primary, secondary, and sometimes tertiary scrubbing systems, however, also control particulate matter emissions.

The control technologies that can be applied to these PM emission sources include:

- cyclone systems;
- wet scrubbing systems;
- bag filters; and
- electrostatic precipitators.

In practice, however, electrostatic precipitators have not been the technology of choice. Moreover, the use of bag filters has been limited to the cooler exhausts from certain processes and product screening, milling and handling ventilation system exhausts. This is primarily because the major PM emission points (the reactor granulator exhausts, dryer exhausts, and cooler exhausts on certain processes) are also emission points for other pollutants. In particular, gaseous flouride emissions (GTSP and DAP) and gaseous ammonia emissions (DAP only) are largely unaffected by electrostatic precipitators or baghouses. In addition, the moisture in the reactor and dryer exhaust streams and the sticky nature of the particulate matter in these streams complicates the use of bag filter devices. Consequently, PM control technologies applicable to DAP and GTSP production processes are realistically limited to dry cyclone systems, wet scrubbing systems, and bag filters (for dry materials handling sources only).

Dry cyclone systems are routinely employed on dryer, cooler, screens, and milling operation exhausts to recover entrained product that otherwise may be lost. As such, the cyclone systems are as much a part of the process as they are control equipment.

Controls in place were estimated in a survey of 14 plants (25 DAP and 14 GTSP processes) based on state air permit files and conversations with plant personnel. Although 100 percent of the DAP and GTSP production in the United States is not represented in the survey, based on published production capacity data, greater than 90 percent of domestic production is represented. It was found that primary scrubbing systems are employed on 100 percent of the existing processes. Venturi scrubbers make up about 60 to 95 percent of the primary scrubbers. In addition, secondary scrubbing systems are employed on about 60 to 80 percent of the existing processes. About half of the secondary scrubbers in the industry are packed bed scrubbers. Tertiary scrubbers also are employed on about 8 to 15 percent of the DAP process units (i.e. reactors, dryers, etc.) and 28 percent of the GTSP process units.

6.2.4 Radionuclide Emission Measurements

EPA has measured radionuclide emission in particulate stack releases at two wet process phosphate fertilizer plants (EPA78). The samples were collected on product dryer stacks in accordance with EPA guidelines established in the Code of Federal Regulations, Title 40, Part 60. The annual emission rates based on these measurements are listed in Table 6.2-1.

6.2.5 Reference Facility

Table 6.2-2 describes the parameters of a reference wet process phosphate fertilizer plant which are used to estimate the radionuclide emissions to the atmosphere and the resulting health impacts. The reference plant produces both diammonium phosphate (DAP) and granular triple superphosphate (GTSP) from phosphoric acid derived from phosphate rock. The radionuclide emissions to air from the DAP and GTSP process stacks of the reference facility are listed in Table 6.2-3. The emissions are representative of plants using only primary scrubbers to control DAP and GTSP process off gases.

Table 6.2-1. Radionuclide stack emissions at wet process phosphate fertilizer plants (EPA78)

Parameter	TSP dryer Plant A	TSP dryer Plant B	DAP dryer Plant B
Total particulates (g/y)	2.0E+7	1.2E+7	1.5E+7
Operating time (hr/y)	4.6E+3	7.4E+3	7.5E+3
Stack emissions (Ci/y)			
Uranium-234	1.1E-4	3.0E-4	2.6E-3
Uranium-235	ND	2.0E-5	1.9E-4
Uranium-238	9.0E-5	2.7E-4	3.3E-3
Thorium-227	ND	ND	ND
Thorium-228	4.0E-5	3.0E-5	8.0E-5
Thorium-230	9.0E-5	2.5E-4	3.0E-3
Thorium-232	ND	7.0E-5	5.0E-5
Radium-226	3.0E-5	2.2E-4	2.6E-4
Polonium-210	6.3E-4	NA	NA

ND Not detectable.
NA Not available.

6.2.6 Health Impact Assessment of Reference Plant

The estimated annual radiation doses from radionuclide emissions from the reference wet process phosphate fertilizer plant are listed in Table 6.2-4. These estimates are for a model site in central Florida with a regional population of 1.4E+6. The maximum exposed individual is located 1500 meters south of the reference plant.

Table 6.2-5 presents estimates of the individual lifetime risk and the number of fatal cancers per year of operation from these doses.

The lifetime risks to the maximum individual is estimated to be about 5.E-6 and the number of fatal cancers per year of operation is estimated to be 1.E-3. These risks result primarily from doses to the lung from inhalation of radioactive particulates released from fertilizer production.

6.2.7 Alternative Control Technology

All wet process phosphate fertilizer plants use primary scrubbers on the DAP and GTSP exhausts. The annualized costs and risk reduction of adding alternative controls to the reference wet process phosphate fertilizer plant are shown in Table 6.2-6.

Table 6.2-2. Reference wet process phosphate fertilizer plant

Parameter	Process	
	DAP	GTSP
Production rate (MT/y)	5.2E+5	2.7E+5
Operating factor (hr/y)	8160	8160
Radionuclide content of product (pCi/g)[(a)]		
Uranium-238, uranium-234, thorium-230	60	60
Radium-226	5	20
Lead-210, polonium-210	30	30
Stack parameters		
Height (meters)	40	40
Diameter (meters)	2	2
Exit gas velocity (m/s)	10	10
Exit gas temperature (°C)	60	60
Type of control system	Venturi scrubber	Venturi scrubber
Particulate emission rate (g/MT)	164	100

(a) Data from EPA78.
DAP Diammonium phosphate.
GTSP Granular triple superphosphate.

Table 6.2-3. Radionuclide emissions from the reference wet process phosphate fertilizer plant

Radionuclide	Emissions (Ci/y)		
	DAP	GTSP	Total
Uranium-238	5.1E-3	1.6E-3	6.7E-3
Uranium-234	5.1E-3	1.6E-3	6.7E-3
Thorium-230	5.1E-3	1.6E-3	6.7E-3
Radium-226	4.3E-4	5.4E-4	9.7E-4
Lead-210	2.6E-3	8.1E-4	3.4E-3
Polonium-210	2.6E-3	8.1E-4	3.4E-3

DAP Diammonium phosphate.
GTSP Granular triple superphosphate.

Table 6.2-4. Radiation dose rates from radionuclide emissions from the reference wet process phosphate fertilizer plant

Organ	Maximum individual (mrem/y)	Regional population (Person-rem/y)
Lung	1.2	2.4E+1
Endosteal	2.2	4.1E+1
Red marrow	1.5E-1	2.7
Kidney	6.3E-2	1.3
Weighted sum	4.1E-1	8.0

Table 6.2-5. Fatal cancer risks due to radioactive emissions from reference wet process phosphate fertilizer plant

Source	Lifetime risk to maximum individual	Regional population fatal cancers/y of operation
DAP and GTSP process emissions	5E-6	1E-3

6.2.8 Total Health Impact of Wet Process Phosphate Fertilizer Plants

Wet process phosphate fertilizer plants release about 1500 MT per year of particulates from the DAP and GTSP process stacks with the existing control systems. This amount of particulate matter contains about 90 mCi each of uranium-238, uranium-234, and thorium-230 and lesser quantities of radium-226, polonium-210, and lead-210. This estimate is based on the conservative assumption that the specific activity (pCi/g) of the particulate material released is the same as DAP and GTSP fertilizers. These emissions are estimated to cause about 0.02 fatal cancers per year. This estimate is based on a ratio of the amount of particulate material released from all plants to the amount released from the reference plant in a manner similar to that shown in Section 6.1.8.

6.2.9 Costs and Risk Reductions for Retrofitting Existing Plants

The annualized costs to the industry to retrofit existing phosphate fertilizer plants with secondary scrubbers are shown in Table 6.1-7. To retrofit existing DAP process exhausts with packed bed scrubbers (28 percent of the existing production capacity) would cost an additional $3 million per year and would avoid 0.002 fatal cancers per year, or a cost of $1.5 billion per fatal cancer avoided. Retrofitting GSTP process exhausts with packed bed scrubbers (19 percent of existing production capacity) would cost an additional $500,000 per year and would avoid 0.0008 fatal cancers per year, or a cost of $6.5 billion per fatal cancer avoided.

Table 6.2-6. Annualized costs and risk reductions of alternative controls for the reference wet process phosphate fertilizer plant(a)

Process	Control option(b)	Emission rate (g/MT)	Total annual cost(c) ($1,000)	Fatal cancer risks		Cost/fatal cancer avoided (in millions)
				Individual lifetime risk	Population (cancers/y of operation)	
DAP	Existing	164		4E-6	8E-4	
	Alternative	100	500	2E-6	5E-4	1.7E+3
GTSP	Existing	100		1E-6	2E-4	
	Alternative	79	300	8E-7	1.6E-4	7.5E+3

(a) Source: TRW82.

(b) Existing controls are venturi scrubbers. Alternative controls are packed bed scrubbers in series with venturi scrubbers.

(c) Particulate material emission rate.

(d) Incremental cost for installing and operating alternative control systems, i.e., additional costs for installing and operating packed bed scrubbers.

Table 6.2-7. Industry annualized costs and risk reductions for adding secondary scrubbers to existing wet process phosphate fertilizer plants(a)

Process	Total cost (millions)(b)	Fatal cancers avoided/y	Cost/fatal cancer avoided (in millions)
DAP	3	2E-3	1.5E+3
GTSP	0.5	8E-5	6.3E+3

(a) TRW82.

(b) Incremental cost of installing and operating packed bed scrubbers in series with existing venturi scrubbers. Twenty-eight percent of DAP production capacity and 19 percent of GTSP production capacity require retrofit.

REFERENCES

EPA78 Environmental Protection Agency, Radiation Dose Estimates due to Air Particulate Emissions from Selected Phosphate Industry Operations, ORP/EERF-78-1, Office of Radiation Programs, Montgomery, Alabama, 1978.

EPA79 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, EPA-520/7-79-006, Office of Radiation Programs, Washington, D.C., 1979.

TRW82 Industry and Particulate Matter Control Technology Information for Diammonium Phosphate and Granular triple Superphosphate manufacture. A report prepared by TRW Environmental Division for the Environmental Protection Agency, Dec 15, 1982.

6.3 Elemental Phosphorus Plants

6.3.1 General Description

About ten percent of the marketable phosphate rock mined in the United States is used for the production of elemental phosphorus. Elemental phosphorus is used primarily for the production of high grade phosphoric acid, phosphate-based detergents, and organic chemicals. In 197,7 approximately 285 thousand metric tons of elemental phosphorus were produced from 4 million metric tons of phosphate rock.

Phosphate rock contains appreciable quantities of uranium and its decay products. The uranium concentration of phosphate rock ranges from about 20 to 200 ppm, which is 10 to 100 times higher than the uranium concentration in natural rocks and soil (2 ppm). The radionuclides of significance which are present in phosphate rock are: uranium-238, uranium-234, thorium-230, radium-226, radon-222, lead-210, and polonium-210. Because phosphate rock contains elevated concentrations of these radionuclides, handling and processing this material can release radionuclides into the air in the form of dust particles. More importantly for elemental phosphorus plants, heating the phosphate rock to high temperatures in calciners and electric furnances can volatilize lead-210 and polonium-210, resulting in the release of large quantities of these radionuclides into the air.

There are 8 elemental phosphorus plants in the United States--located in Florida, Idaho, Montana, and Tennessee. Table 6.3-1 shows the owners, locations, and the estimated elemental phosphorus production rates for these plants.

6.3.2 Process Description

Phosphate rock which has been crushed and screened is fed into calciners where it is heated to the melting point, usually 1300° C. The calcining serves two purposes: (1) it burns any organic matter present in the rock, and (2) it transforms the finely divided rock into large stable agglomerates or nodules which are needed for proper operation of the reduction furnaces. The hot nodules are passed through coolers and then to storage bins prior to being fed to electric furnaces. The furnace feed consists of the nodules, silica and coke. The proper amount of silica is needed to form slag with the flow properties necessary to facilitate removal from the furnace. Coke is added as a carbon source to reduce the calcium phosphate to elemental phosphorus. A simplified chemical equation for the electric furnace reactor is as follows:

$$2Ca_3(PO_4)_2 + 6SiO_2 + 10C = P_4 + 10CO + 6CaSiO_3 \quad (1)$$

In addition, the iron naturally present in the rock reacts with some of the phosphorus to produce FeP. The blended furnace feed enters the furnaces continually from the top and progresses downward until reaching the molten layer on the bottom. Phosphorus and carbon monoxide (CO) are driven off as gases and are vented near the top of the furnace. The slag and FeP which are continually collecting in the furnace are periodically "tapped off."

Furnace off-gasses pass through dust collectors and then through water spray condensors. Phosphorus is cooled to the molten state in the condensors. The mix of phosphorus and water--phossy water--and mud go to a processing system where phosphorus is separated and piped to storage. The clean off-gases leaving the condensors contain a high concentration of CO and are used as fuel in the calciners. A flow diagram of the process is shown in Figure 6.3-1.

Table 6.3-1. Location and size of elemental phosphorus plants(a)

Location	Company	Capacity (MT/y of Phosphorus)
Florida		
Pierce	Mobil (Electro Phos.)	1.8E+4
Tarpon Springs(b)	Stauffer Chemical Co.	2.3E+4
Idaho		
Pocatello	FMC Corporation	1.3E+5
Soda Springs	Monsanto Chemical Co.	1.0E+5
Montana		
Silver Bow	Stauffer Chemical Co.	3.8E+4
Tennessee		
Columbia	Hooker Chemical Co.	4.1E+4
Columbia	Monsanto Chemical Co.	1.2E+5
Mt. Pleasant	Stauffer Chemical Co.	4.5E+4

(a) Data from TRI81.

(b) Plant is presently shut down.

6.3.3 Control Technology

Emissions from calciners are typically controlled by low energy scrubbers. Emissions from nodule coolers and transfer points and furnace tap holes are controlled by either fabric filters or wet scrubbers. Screening plant emissions are usually controlled by fabric filters. Fugitive dust emissions and radon gas emissions are not controlled.

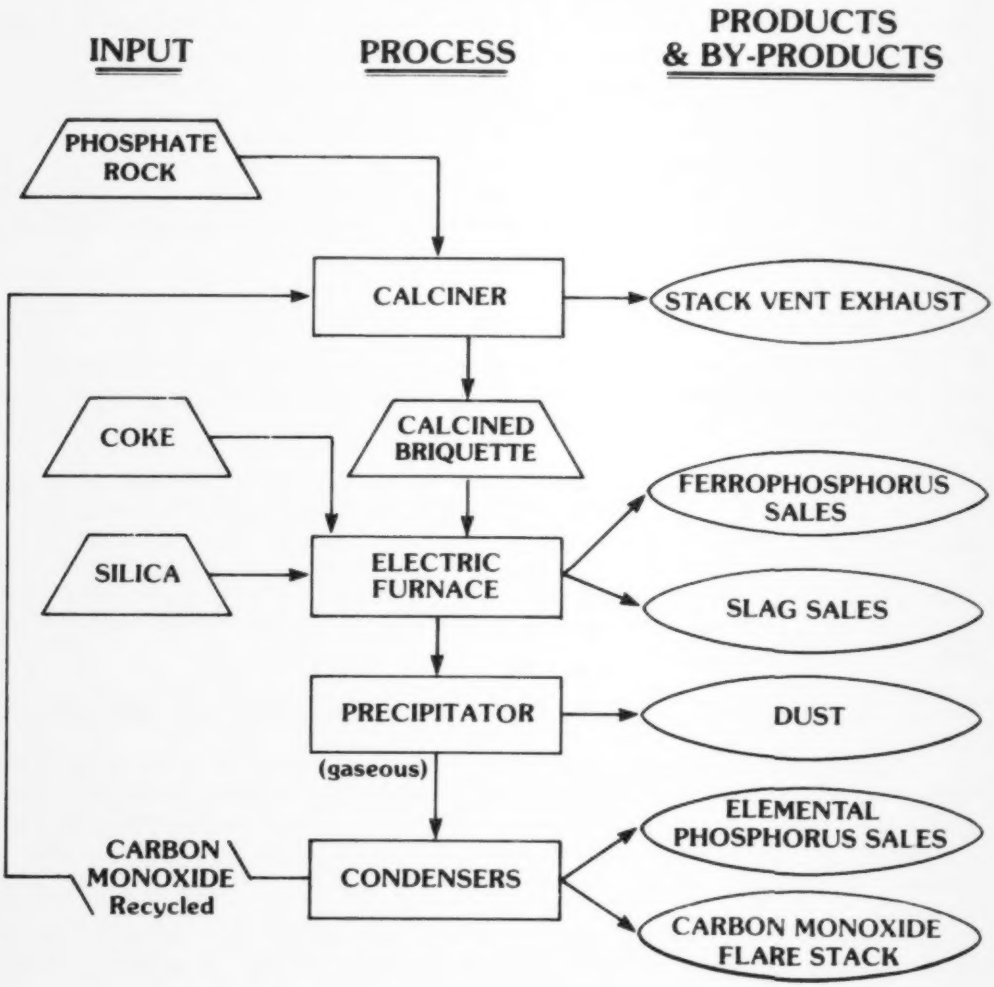

INPUT
PROCESS
PRODUCTS & BY-PRODUCTS
PHOSPHATE ROCK
CALCINER
STACK VENT EXHAUST
COKE
CALCINED BRIQUETTE
FERROPHOSPHORUS SALES
SILICA
ELECTRIC FURNACE
SLAG SALES
PRECIPITATOR
DUST
(gaseous)
ELEMENTAL PHOSPHORUS SALES
CARBON MONOXIDE Recycled
CONDENSERS
CARBON MONOXIDE FLARE STACK

Figure 6.3-1. Flow diagram of the thermal process for production of elemental phosphorus.

6.3.4 Radionuclide Emission Measurements

EPA has measured the radionuclide emissions from three elemental phosphorus plants (EPA77, An81a, An81b). The stack emission rates measured during these studies are summarized in Table 6.3-2.

All of the radionuclides are released as particulates except for radon-222, which is released as a gas. Lead-210 and polonium-210 are the particulate form radionuclides released in the largest quantities. Essentially all of the radon-222 and greater than 95 percent of the lead-210 and polonium-210 emitted from these facilities are released from the calciner stacks (plants B and C). The high temperature of the calciners and reduction furnaces volatilize the lead-210 and polonium-210 from the phosphate rock, resulting in the release of much greater quantities of these radionuclides than the uranium, thorium and radium radionuclides.

6.3.5 Reference Facility

Table 6.3-3 describes the parameters of a reference elemental phosphorus plant which are used to estimate the radioactive emissions to the atmosphere and the resulting health impacts.

The radioactive emissions to air from the reference facility are listed in Table 6.3-4. These emissions are representative of a plant with no radon control which releases 10 percent of the polonium-210 and 5 percent of the lead-210 in the phosphate rock processed. These are similar to the releases estimated for Plant C in Table 6.3-2 and are believed to be typical of plants operating with low energy scrubbers on the calciner exhausts.

6.3.6 Health Impact Assessment of Reference Elemental Phosphorus Plant

The estimated annual radiation doses and working level exposures from radionuclide emissions from the reference elemental phosphorus plant are listed in Tables 6.3-5 and 6.3-6. These estimates are for a southeastern Idaho site with a regional population of 1.4E+5. The maximum individual is assumed to be located 1500 meters from the plant.

Table 6.3-7 presents estimates of the maximum individual lifetime risk and the number of fatal cancers to the regional population from these doses and working level exposures.

The lifetime risk to the maximum individual is estimated to be 1E-4 and the total number of fatal cancer per year of operation is estimated to be 8E-3. These risks result primarily from polonium-210 emissions from the calciner stack. The risks from radon-222 stack emissions are small (less than 5 percent) compared to the risks from the particulate emissions.

Table 6.3-2. Radionuclide stack emissions measured at elemental phosphorus plants(a)

Parameter	Plant A	Plant B	Plant C
Rock processing rate (MT/y)	1.6E+6	5.3E+5(b)	1.7E+6(b)
Uranium-238 concentration of rock (pCi/g)(c)	22.0	27.0	5.0
Calciner stacks emission rate (Ci/y):			
Uranium-238	1.2E-3	2.4E-4	2.2E-3
Uranium-234	1.3E-3	2.0E-4	3.2E-3
Thorium-230	2.2E-3	1.2E-4	1.4E-3
Radium-226	1.3E-3	3.5E-4	2.1E-3
Radon-222	-	8.0	9.6
Lead-210	3.0E-3	2.8E-1	4.8E-1
Polonium-210	6.9	2.0E-1	7.5E-1
Other stacks emission rate (Ci/y):			
Uranium-238	4.0E-2	6.2E-4	1.0E-2
Uranium-234	4.6E-2	7.0E-4	1.0E-2
Thorium-230	5.3E-3	1.2E-3	1.2E-2
Radium-226	5.9E-3	1.1E-3	9.0E-3
Radon-222	-	ND	ND
Lead-210	1.5E-2	2.5E-3	ND
Polonium-210	4.0E-1	5.9E-3	2.7E-3
Fraction of input radionuclides emitted:			
Uranium-238	1.2E-3	6.0E-5	1.4E-3
Uranium-234	1.4E-3	6.2E-5	1.5E-3
Thorium-230	2.1E-4	9.0E-5	1.5E-3
Radium-226	2.0E-4	9.8E-5	1.7E-3
Radon-222	-	5.7E-1	1.1
Lead-210	5.1E-4	2.0E-2	5.6E-2
Polonium-210	2.1E-1	1.4E-2	8.8E-2

(a) Emissions are in particulate form except for radon-222 which is released in gaseous form.

(b) These processing rates are based on plant production capacities listed in Table 6.3-1 and a factor of 14 MT of phosphate rock per MT of elemental phosphorus.

(c) Uranium-238 and its daughter products are assumed to be present in equilibrium in the rock.

Table 6.3-3. Reference elemental phosphorus plant

Parameter	Value
Phosphate rock processing rate	1.6E+6 MT/y
Elemental phosphorus production rate	1.2E+5 MT/y
Operating factor	7000 h/y
Number of calciners	2
Uranium-238 concentration of phosphate rock	25 pCi/g[a]
Stack parameters:[b]	
Height	30 meters
Diameter	2 meters
Exit gas velocity	15 meters/sec
Exit gas temperature	60° C
Emission control system	low energy scrubber
Particulate emissions:	
Calciner stack	0.25 kg/MT
Other stacks	0.25 kg/MT

[a] Uranium-238 is assumed to be in equilibrium with its daughter products.

[b] Parameters for the calciner stack.

Table 6.3-4. Radionuclide emissons from the reference elemental phosphorus plant

Radionuclide	Emissions (Ci/y)	
	Calciner stack	Other stacks
Uranium-238	1E-2	1E-2
Uranium-234	1E-2	1E-2
Thorium-230	1E-2	1E-2
Radium-226	1E-2	1E-2
Radon-222	4E+1	-
Lead-210	2.0	1E-2
Polonium-210	4.0	1E-2

6.3.7 Existing Emission Standards and Air Pollution Controls

There are no radionuclide emission standards for elemental phosphorus plants. However, the states regulate particulate emissions from elemental phosphorus plants. Although these plants are not subject to industry-specific standards, they must comply with the general process source standards set forth in each State Implementation Plan (SIP). Identical standards have been adopted for plants in Idaho, Montana, and Tennessee (existing plants only); slightly more stringent standards have been set in Florida. Table 6.3-8 shows the particulate emission limits for general process sources for these States.

6.3.8 Alternative Control Technology

The costs and risk reductions achieved by adding alternative controls to the calciner stacks of the reference plant to reduce lead-210 and polonium-210 emissions are shown in Table 6.3-9. The existing baseline level of control for all plants is a low energy scrubber. However, primary and secondary scrubbers in series are already in use in at least one plant.

Table 6.3-5. Radiation dose rates from radionuclide emissions from the reference elemental phosphorus plant

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	36	136
Red marrow	4	13
Kidney	45	133
Endosteal	23	70
Weighted Sum	15	52

The costs presented in Table 6.3-9 are the annualized costs for installing and operating the alternative control systems. Because information is not available on the operating costs of the existing systems, we could not estimate the incremental costs above the existing costs for these alternative controls. The capital and operating unit costs used in estimating the costs for the reference plant are presented in Table 6.3-10. The values of annualized costs in Table 6.3-9 are twice the values in Table 6.3-10 because the reference plant operates with two calciners.

Table 6.3-6. Annual radon decay product exposures from radon-222 emissions for the reference elemental phosphorus plant

Source	Maximum individual (WL-y)	Regional population (person-WL-y)
Plant Stacks	3.2E-6	1.3E-2

Table 6.3-7. Fatal cancer risks due to radioactive emissions from the reference elemental phosphorus plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Particulates	1E-4	8E-3
Radon-222	5E-6	3E-4
Total	1E-4	8E-3

6.3.9 Total Health Impact of Elemental Phosphorus Industry

The estimated total number of fatal cancers caused by all elemental phosphorus plants is about 0.05 per year. This estimate was derived from the ratio of the capacity of the reference plant to the capacity of each individual plant taking into consideration the population density of the individual plant site and the radionuclide concentration of the processed phosphate rock (see Table 6.3-11). Because this estimate is based on plant capacity and not production rates, it represents an upper bound estimate of the health impact.

Table 6.3-8. Particulate emission limits for general process sources(a)

State	Particulate emission limits (lbs/h)		
	30 tons/h(b)	100 tons/h	500 tons/h
Florida	30	36	47
Tennessee, Idaho, and Wyoming	40	51	79

(a)Data from EPA79.
(b)Material processing rate.

Table 6.3-9. Costs and risk reductions of adding alternative controls to the calciner stack of the reference elemental phosphorus plant

Type of control	Emission rate[a] (g/MT)	Level of polonium-210 control (%)	Annual cost[b] ($1000)	Fatal cancer risks: Individual lifetime risk	Fatal cancer risks: Fatal cancers/y
Low energy scrubber	250-500	90[c]	[d]	1E-4	8E-3
Medium energy scrubber	150	94[e]	1,700	6E-5	5E-3
High energy scrubbers	50	98[c]	2,000	2E-5	2E-3

[a] Particulate matter emission rate.
[b] Reference plant has two (2) calciner units.
[c] Based on emission measurement data from Table 6.3-2.
[d] Existing control.
[e] Estimated value.

Table 6.3-10. Capital and operating costs for alternative control systems for calciner units of the reference elemental phosphorus plant

Type of control	Installed capital cost ($1000)	Annual capital cost ($1000)	Annual operating cost ($1000)	Total annualized cost ($1000)
Medium energy scrubber[a]	1,300	260	600	860
High energy scrubber [b]	1,600	320	700	1,020

[a] 15" water gauge.
[b] 30" water gauge.

Table 6.3-11. Total health impact of radionuclides emissions from elemental phosphorus industry

Location of plants	Number of plants	Plant capacity[(a)] (MT/y)	Radionuclide concentration (pCi/g)	Regional population (Persons/km^2)	Fatal cancers/y
Idaho	2	3.5E+6	25	7	2E-2
Tennessee	3	2.9E+6	5	15	6E-3
Florida	1	2.5E+5	45	70	2E-2
Montana	1	5.3E+5	25	5	2E-3
Total					5E-2

(a)Phosphate rock processing rate.

REFERENCES

An81a Andrews V. E., Emissions of Naturally Occurring Radioactivity from Stauffer Elemental Phosphorus Plant, ORP/LV-81-4, EPA, Office of Radiation Programs, Las Vegas, Nevada, August 1981.

An81b Andrews V. E., Emissions of Naturally Occurring Radioactivity from Monsanto Elemental Phosphorus Plant, ORP/LV-81-5, EPA, Office of Radiation Programs, Las Vegas, Nevada, August 1981.

EPA77 Environmental Protection Agency, Radiological Surveys of Idaho Phosphate Ore Processing--The Thermal Plant, ORP/LV-77-3, EPA, Office of Radiation Programs, Las Vegas, Nevada, 1977.

EPA79 Environmental Protection Agency, Phosphate Rock Plants, Background Information on Proposed Standards, EPA-450/3-79-0017, USEPA Research Triangle Park, N.C., September 1979.

TRI81 Teknekron Research, Inc., Draft, Partial and Supplemental Background Information Document--Primary Pyrometallurgical Extraction Process, Report to Environmental Agency under Contract No. 68-01-5142, USEPA Docket Number A-79-11, May 1981.

Chapter 7: MINERAL EXTRACTION INDUSTRY FACILITIES

Metal Mines, Mills, and Smelters

Almost all industrial operations involving the removal and processing of ores to recover metals release some radionuclides into air. This chapter presents an assessment of the radionuclide emissions from the aluminum, copper, zinc, and lead industries. These industries were studied because they involve the processing of large quantities of ore and because they all involve pyrometallurgical processes which have the greatest potential for radionuclide emissions. Two types of assessments are presented in this chapter. One is an assessment of emissions from a reference facility which, in each case, involves a high temperature operation. The information for these assessments is taken directly from a report prepared for EPA by Teknekron Research, Inc. (TRI81), except for the dose and risk calculations for the zinc and copper smelters which were made using methodology described in Appendices A and B..

The second approach is an assessment of emissions measured by EPA at surveyed facilities. Reports on these emission measurements became available subsequent to the assessments of the reference facilities. Assessments are presented for an alumina plant, an aluminum reduction plant, an underground copper mine and mill, an open pit copper mine and mill, and a zinc mine and mill.

7.1 Aluminum Industry

7.1.1 General Description

Bauxite is the principal aluminum ore found in nature. The ore is processed at the mine to produce alumina (Al_2O_3), the basic feed in the aluminum reduction process. Aluminum metal is produced by the reduction of alumina in a molten bath of cryolite. The production of aluminum differs from other primary metals in that no purification of the metal produced in the electric cells is needed; contaminants in the ore are removed in the milling rather than the smelting phase of the process.

Of the 12 domestic companies producing primary aluminum, only Alcoa and Reynolds perform all stages of production, from domestic mining through the primary metal stage. Almost all of the bauxite used in aluminum production is imported. Five other domestic firms own bauxite and/or alumina facilities in other countries and import raw materials. Only five of the twelve firms that own primary aluminum plants also own domestic plants producing the input product, alumina. These five companies (Aluminum Company of America, Kaiser Aluminum and Chemical Corporation, Reynolds Metals Co., Martin Marietta Aluminum Co., and Ormet Corp.) own 73 percent of the current U.S. primary aluminum capacity (St78).

There are currently 32 operating primary aluminum smelters in the United States (Table 7.1-1). With one exception, all of the plants are located in rural areas. Population densities in the vicinities of the plants range from 12 to 62 persons per square kilometer (EPA79).

Table 7.1-1. Location and size of primary aluminum production plants (TRI81)

Location	Company	Capacity (1000 MT/y)
Alabama		
Arkadelphia	Reynolds Metals Company	56
Jones Mills	Reynolds Metals Company	103
Listerhill	Reynolds Metals Company	166
Scottsboro	Revere Copper & Brass Co.	95
Indiana		
Evansville	Aluminum Company of America	239
Kentucky		
Hawesville	National Southwire	148
Sebree	Anaconda Aluminum Company	148
Louisiana		
Chalmette	Kaiser Aluminum & Chemical Corp.	215
Lake Charles	Consolidated Aluminum Corporation	30
Maryland		
Frederick	Eastalco Aluminum Company	145
Missouri		
New Madrid	Noranda	115

Table 7.1-1. Location and size of primary aluminum production plants (Continued)

Location	Company	Capacity (1000 MT/y)
Montana		
Columbia Falls	Anaconda Aluminum Company	148
North Carolina		
Badin	Aluminum Company of America	103
New York		
Massena	Aluminum Company of America	177
Massena	Reynolds Metals Company	104
Ohio		
Hannibal	Ormet Corporation	215
Oregon		
The Dalles	Martin-Marietta Aluminum Co.	75
Troutdale	Reynolds Metals Company	104
Tennessee		
Alcoa	Aluminum Company of America	182
New Johnsville	Consolidated Aluminum Corporation	119
Texas		
Point Comfort	Aluminum Company of America	153
Palestine	Aluminum Company of America	13
Rockdale	Aluminum Company of America	268
San Patricio	Reynolds Metals Company	94
Washington		
Ferndale	Intalco Aluminum Corp.	215
Goldendale	Martin-Marietta Aluminum Company	99
Longview	Reynolds Metals Company	174
Mead	Kaiser Aluminum & Chemical Corp.	182
Ravenswood	Kaiser Aluminum & Chemical Corp.	135
Tacoma	Kaiser Aluminum & Chemical Corp.	66
Vancouver	Aluminum Company of America	95
Wenatchee	Aluminum Company of America	173
Total		4354

7.1.2 Process Description

Of the 32 aluminum reduction plants in the United States, all but one produce aluminum in electric furnaces (cells) by the Hall-Hiroult process. In the Hall-Hiroult process, alumina (Al_2O_3) is reduced electrolytically in a molten bath of cryolite ($NaAlF_6$). The Aluminum Company of America's pilot plant in Palestine, Texas, employs aluminum chloride as the electrolyte.

Two basic types of cells are used by the industry: prebake and Soderberg. The chief difference between the two types is the means by which carbon is supplied to the reduction cells. At prebake plants, both center- and side-worked cells use preformed carbon anodes baked into a solid mass. Soderberg cells use carbon anode paste which is fed to the cell continuously.

Both types of reduction cells are operated at termperatures in excess of 950° C, the melting point of the cryolite. Approximately 2.6 metric tons of raw materials, along with large quantities of electricity, are required to produce 1 MT of aluminum. The breakdown of raw materials is shown in Table 7.1-2.

Table 7.1-2. Raw materials used in producing aluminum (EPA77)

Raw material	MT Feed/MT Al produced
Alumina (Al_2O_3)	1.9
Cryolite ($NaAlF_6$)	0.03-0.05
Aluminum Fluoride (AlF_3)	0.03-0.05
Fluorspar (CaF_2)	0.003
Petroleum Coke	0.455-0.490
Pitch Binder	0.123-0.167
Carbon (cathode)	0.02

The particulate emissions from the process reflect the composition of the feed materials, and include alumina, carbon, cryolite, aluminum fluoride, and trace elements. Generation of particulate emissions varies with the type of cells. At prebake plants, particulate emissions from the anode furnace range from 0.5 to 2.5 kg/MT of aluminum produced, with 1.5 kg/MT being a typical value (EPA76). Particulate emissions generated by the cells vary from 5.95 to 88.5 kg/MT, with 40.65 kg/MT being typical (EPA76).

Quality of Feed Materials

No evidence could be found that the quality of feed materials varies to any significant degree. Radionuclide concentrations for input materials are given in Table 7.1-3.

Table 7.1-3. Radionuclide concentrations of feed materials to aluminum plants (EPA82)

Feed material	Radionuclide concentration (pCi/g)	
	Uranium-238	Thorium-232
Alumina	0.10	< 0.2
Aluminum Fluoride	0.11	< 0.2
Cryolite	0.11	< 0.2

7.1.3 Control Technology For Primary Aluminum Reduction Plants

Controls for emissions from aluminum plants are either primary or secondary controls. Primary controls handle the emissions captured by the cell hoods, while secondary controls are used to treat the entire building effluent, including cell emissions that escape the primary hoods. Primary controls are used at all plants, but secondary controls are generally used only by the plants that employ Soderberg cells (EPA79).

Control devices used for primary control vary widely from plant to plant, and include multicyclones, dry and fluid bed alumina adsorbers followed by fabric filters or electrostatic precipitators, and spray towers with spray screens. Not only do the efficiencies of these devices vary over a considerable range (70-99+ percent), but the collecting hoods for the various types of cells range from less than 80 percent to greater than 95 percent capture efficiency (EPA79). A more detailed discussion of control systems for primary aluminum plants is presented in TRI81.

7.1.4 Radionuclide emissions

Particulate material emitted from an aluminum reduction plant contains radionuclide concentrations (pCi/g) similar to or greater than the concentrations in the alumina processed. Because of the high temperatures of the reduction cells, some radionuclides (particularly lead-210 and polonium-210) may be volatilized and released in greater quantities than the other radionuclides in the alumina. EPA has recently measured the radionuclide emissions from an aluminum reduction plant. The emission estimates for the reference aluminum reduction plant are based on preliminary data from these measurements.

7.1.5 Reference Facility

Table 7.1-4 describes the parameters of a reference aluminum reduction plant which are used to estimate the radionuclide emissions to air and the resulting health impacts.

Since the currently operating facilities have similar particulate emission rates and use roughly the same process and feed stocks, one reference plant characterizes the primary aluminum source category. It uses center-worked prebake cells, the most commonly used equipment now in operation. The capacity chosen (136,000 metric tons/y of aluminum) is approximately the average size of all existing plants. A capacity factor of 0.94 is applied to the plant, the 1979 industry-wide average (DOI80).

Since no stack parameters were available for the main stack, default values of 30 meters for the height and 1.8 meters for the diameter are used. Exhaust gas flow rates were determined by scaling available flow rates linearly with the difference in capacity between an actual facility and the reference plant.

As of 1975, 95 percent of all plants had at least primary control of particulate emissions, and 73 percent were reported to have "best" primary control; only 11 percent had "best" primary plus secondary control (EPA79). It is presumed that "best" primary control consists of the best available hooding, plus a fluidized-bed scrubber since this unit can achieve the highest reported control efficiencies (97-99 percent removal). Based on this information, the model plant is equipped with a fluidized-bed scrubber for primary control. The plant has no secondary control equipment. As for the anode bake plant, a spray scrubber constitutes the particulate control system.

Radionuclide emissions for the reference plant were based on actual measurements of radionuclide concentrations in the particulate emissions from an existing plant. The measurement data were scaled to take into account the differences in capacity and particulate emission rate between the actual and the reference plant. The resulting releases are listed in Table 7.1-5.

7.1.6 Health Impact Assessment of Reference Plant

The estimated annual radiation doses from radionuclide emissions from the reference aluminum reduction plant are listed in Table 7.1-6. These estimates are for a rural site with a regional population of 2.7E+5 (rural southeastern site from TRI81).

Table 7.1-7 presents estimates of the maximum individual lifetime risk and number of fatal cancers per year of operation from these doses.

7.1.7 Health Impact Assessment of Surveyed Plants

EPA has recently carried out radionuclide measurements at both an alumina plant and an aluminum reduction plant. Reports on these studies (EPA82) were completed subsequent to the analysis of the reference plant assessed in the previous sections. These reports

Table 7.1-4. Reference aluminum reduction plant (TRI81)

Parameter	Value
Capacity	136,000 MT/y aluminum
Capacity factor	0.94
Type of equipment	Center-worked prebake cells
Stack Parameters:	
Main stack	
Height	30 m
Diameter	1.8 m
Exit gas velocity	104.7 m/s
Exit gas temperature	93° C
Roof monitor	
Height	10 m
Diameter	1.2 m
Exit gas velocity	0.01 m/s
Exit gas temperature	37° C
Anode bake plant	
Height	30 m
Diameter	1.8 m
Exit gas velocity	4.5 m/s
Exit gas temperature	96° C

Table 7.1-5. Radionuclide emissions from the reference aluminum reduction plant (TRI81)

Radionuclide	Emission (Ci/y)		
	Main stack	Roof monitor	Anode bake plant
Uranium-238	8.6E-3	8.1E-9	8.0E-5
Uranium-234	8.6E-3	8.1E-9	8.0E-5
Thorium-230	1.8E-2	3.8E-8	4.0E-5
Radium-226	2.9E-3	7.4E-9	6.0E-5
Lead-210	6.9E-2	2.0E-7	2.0E-4
Polonium-210	6.9E-2	2.0E-7	2.0E-4
Thorium-232	1.4E-2	2.9E-8	3.2E-5
Radium-228	1.4E-2	2.9E-8	3.2E-5

provide information on the radionuclide concentrations of process samples and annual radionuclide emission rates to air. The results of these measurement studies and an assessment of the health risks from these emissions for a generic site are presented in this section.

Alumina Plant

The alumina plant studied uses a modified "American Bayer" process. The uranium-238 and thorium-232 concentration measured in the process samples are listed in Table 7.1-8. The estimated annual radionuclide emissions from this plant are listed in Table 7.1-9.

The bauxite ore was elevated in both uranium-238 and thorium-232 with concentrations of 6.8 and 5.5 pCi/g. The low radioactivity of alumina is reflected in the low radionuclide emissions from the alumina kilns. Particulate emissions of radionuclides from the red mud sinter kiln were below measurable concentrations except for lead-210 and polonium-210. The high temperatures of the kilns caused a large fraction of these radionuclides to be volatilized. Emissions of the two nuclides were essentially equal with 7.8 mCi/y for lead-210 and 9.3 mCi/y for polonium-210. The estimated radiation doses and health risks from these emissions are listed in Tables 7.1-10 through 7.1-12. These estimates are for a rural site with a regional population of 6E+5.

Table 7.1-6. Radiation dose rates from radionuclide emissions from the reference aluminum reduction plant (TRI81)

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	2.5	4.8
Red marrow	4.5E-1	1.3
Endosteal	7.1	1.8E+1
Muscle	2.2E-2	2.9E-1
Liver	5.3E-2	1.2

Table 7.1-7. Fatal cancer risks due to radionuclide emissions from the reference aluminum reduction plant (TRI81)

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Aluminum reduction plant	9E-6	3E-4

Table 7.1-8. Radionuclide concentrations in surveyed alumina plant process samples (EPA82)

Sample	Concentration (pCi/g)	
	Uranium-238	Thorium-232
Bauxite ore	6.8	5.5
Alumina kiln feed	0.05	0.05
Alumina product	0.28	0.2
Red mud	7.5	5.0
Brown mud	5.5	12.5

Table 7.1-9. Radionuclide emissions from the surveyed alumina plant (EPA82)

Radionuclide	Emissions (Ci/y)	
	Alumina kilns	Red mud kilns
Uranium-238	6.8E-5	
Uranium-234	6.8E-5	
Radium-226	5.5E-5	
Radon-222		2.0
Lead-210		7.8E-3
Polonium-210		9.3E-3

Table 7.1-10. Radiation dose rates from radioactive particulate emissions from the surveyed alumina plant(a)

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	2.5	1.9
Red marrow	2.7E-1	1.2E-1
Endosteal	1.3	4.3E-1
Breast	1.6E-1	8.7E-2
Liver	8.9E-1	3.8E-1
Weighted sum	9.8E-1	6.7E-1

(a)Based on a 10-meter stack height.

Table 7.1-11. Annual radon decay product exposures from radon-222 emissions from the surveyed alumina plant

Source	Maximum individual (WL-y)	Regional population (person-WL-y)
Stack	4.6E-6	7.3E-3

Table 7.1-12. Fatal cancer risks from radionuclide emissions from the surveyed alumina plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Particulates	1E-5	1E-4
Radon-222	8E-6	2E-4
Total	2E-5	3E-4

Aluminum Reduction Plant

The aluminum reduction plant studied uses the "Hall" reduction process. The uranium-238 and thorium-232 concentrations measured in the process samples are listed in Table 7.1-3. The estimated annual radionuclide emissions from the plant are listed in Table 7.1-13. Only lead-210 and polonium-210 were present in measurable quantities in plant emissions. The high temperatures involved in the process cause these radionuclides to be volatilized. The estimated annual radiation doses from these emissions are presented in Tables 7.1-14. These estimates are for a rural site with a regional population of 6E+5. The maximum individual lifetime risk and number of fatal cancers per year of operation from these doses are shown in Table 7.1-15.

Table 7.1-13. Radionuclide emissions from the surveyed aluminum reduction plant (EPA82)

Radionuclide	Emissions (Ci/y)
Lead-210	3.2E-2
Polonium-210	2.7E-2

Table 7.1-14. Radiation dose rates from radionuclide emissions from the surveyed aluminum reduction plant[a]

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	6.0E-1	4.6
Red marrow	1.7E-1	3.6E-1
Endosteal	1.0	1.6
Breast	9.2E-2	2.4E-1
Liver	6.1E-1	1.2
Kidney	1.6	4.2
Spleen	2.4	6.8
Weighted sum	3.3E-1	1.7

(a)Based on a 36-meter stack height.

Table 7.1-15. Fatal cancer risks from radionuclide emissions from the surveyed aluminum reduction plant

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Particulates	3E-6	3E-4

REFERENCES

DOI80	U.S. Department of the Interior, 1980, Mineral Commodity Summaries, Bureau of Mines, January 1980.
EPA76	Environmental Protection Agency, Compilation of Air Pollution Emission Factors, Second Ed., Part B, AP-42, Feburary 1976.
EPA77	Environmental Protection Agency, Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions, EPA-450/3-77-010, March 1977.
EPA79	Environmental Protection Agency, Primary Aluminum: Draft Guidelines for Control of Flouride Emissions from Existing Primary Aluminum Plants, EPA-450/2-78-049, February 1979.
EPA82	Environmental Protection Agency, Emissions of Naturally Occurring Radioactivity from Aluminum and Copper Facilities, EPA 520/6-82-018, Las Vegas, Nevada, November 1982.
St78	Stamper J.W. and Kurtz H.F., Mineral Commodity Profile-Aluminum, U.S. Department of the Interior, Bureau of Mines, Washington, D.C.
TRI81	Teknekron Research, Inc., Draft, Partial and Supplemental Background Information Document--Primary Pyrometallurgical Extraction Process, Report to Environmental Agency under Contract No. 68-01-5142, USEPA Docket Number A-79-11, May 1981.

7.2 Copper Industry

7.2.1 General Description

Copper ores are milled to produce a concentrate containing copper, sulfur, iron, and some insoluble material (primarily silica and aluminum). This concentrate is the basic feed to the copper smelter that eventually produces the refined copper product. Copper mills and smelters are located near copper mines. Copper concentrates and precipitates are generally smelted by melting the charge and suitable fluxes in a reverberatory furnace. Prior to smelting, part or all of the concentrates may receive a partial roast to eliminate some of the sulfur and other impurities.

The 15 operating primary copper smelters in the United States and their capacities are listed in Table 7.2-1. Total production of primary copper in 1978 was 1.5 million metric tons (Sc79).

All primary copper smelters are located in rural areas with low population densities. Ninety percent of U.S. copper smelter capacity is located in the arid and semi-arid climates of Arizona, Montana, Nevada, New Mexico, Texas, and Utah. The other 10 percent are in Washington, Michigan, and Tennessee, areas of moderate-to-high precipitation. The sites tend to be quite large and generally contain associated mining and milling operations.

Most companies perform all production processes from mining through refining. Seven of the eight companies that own smelters also operate mines and own refineries; Cities Services, which owns the smallest of the smelters, is the only exception (Sc79).

7.2.2 Process Description

The three major steps in the smelting of copper are roasting, smelting, and converting. All of these processes result in releases of sulfur dioxide and particulate matter in process off-gas. Each step in the smelting process is described below.

Roasting

Roasting is the first step in the process of copper smelting. In the roaster, copper ore concentrates are heated to a high temperature (550° C) in an oxidizing atmosphere which partially drives off some of the sulfur as sulfur dioxide (in addition to producing particulate emissions). Seven of the fifteen domestic copper smelters have roasters; four plants feed ore concentrates to a rotary dryer to reduce moisture before smelting; and three feed concentrates directly to the furnace with no pretreatment.

Table 7.2-1. Primary Copper Smelters in the United States, 1978 (TRI81)

Plant location	Company	Capacity (1000 MT)	First year of operation
Arizona			
Hayden	ASARCO, Inc.	163	1890
Miami	Inspiration Consolidated	136	1951[a]
Hayden	Kennecott Copper Corp.	73	1958
San Manuel	Magma Copper Company	181	1950
Morenci	Phelps Dodge Corporation	161	1942
Douglas	Phelps Dodge Corporation	115	1910
Ajo	Phelps Dodge Corporation	63	1950
Michigan			
White Pine	Copper Range Company	82	1905
New Mexico			
Hurley	Kennecott Copper Corp.	73	1939
New Mexico			
Hidalgo	Phelps Dodge Corporation	127	1976
New York			
McGill	Kennecott Copper Corp.	45	1907
Tennessee			
Copper Hill	Cities Services Company	20	1845
Texas			
El Paso	ASARCO, Inc.	104	1905
Utah			
Garfield	Kennecott Copper Corp. Corporation	254	1907
Washington			
Tacoma	ASARCO, Inc.	91	1890
Total		1688	

(a)Rebuilt as of 1979.

Smelting

All domestic copper smelters use smelting furnaces to melt and react copper concentrate and/or calcine in the presence of silica and limestone flux to form two immiscible liquid layers, one being the slag or waste layer containing most of the iron and silica compounds and the other containing copper and iron sulfide and other metals, referred to a matte copper. Smelting is conducted in either reverberatory or electric furnaces. Reverberatory furnaces are refractory-lined, box-shaped structures heated by either natural gas, oil, or coal. Reverberatory smelting furnaces are more common than electric furnaces. Currently, 2 out of 15 smelters use electric furnaces to smelt copper. Electric furnaces have basically the same construction as reverberatory furnaces.

Converting

The converter processes matte copper from the reverberatory furnace by removing iron compounds and converting copper at high temperatures (550 to 800° C). The resulting blister copper is further purified by processing in a refining furnace and by electrolytic refining .

7.2.3 Control Technology

Of the 15 primary copper smelters currently operating, 11 use reverberatory furnaces and 7 have roasters. Of these seven, four use multi-hearth roasters while the other three use fluid-bed roasters. The actual smelting process used by those plants with reverberatory furnaces does not differ from facility to facility. Acid gas cleanup plants have been installed on all but three currently operating smelters to treat converter off-gases. A cyclone, a water spray chamber, and an electrostatic precipitator (ESP) are used to clean these gases prior to their entering the SO_2 plant. Off-gases from the reverberatory furnace are controlled via an ESP in virtually all of the operating plants. Three of the four multi-hearth roasters currently operating treat their roaster off-gases by using ESPs.

7.2.4 Radionuclide Emission Measurements

Particulate material emitted from a copper smelter contains radionuclides in concentrations (pCi/g) similar to or greater than the ore concentrates. Because of the high temperatures of the roasting and smelting, some radionuclides (particularly lead-210 and polonium-210) may be volatilized and released in greater quantities than the other radionuclides in the ore concentrates.

Very little information is available on radionuclide emissions from copper smelters. EPA has recently surveyed two copper smelters. The preliminary data from these studies were used in estimating radionuclide emissions from the reference copper smelter.

7.2.5 Reference Facility

Table 7.2-2 describes the parameters of a reference copper smelter which were used to estimate the radioactive emissions to the atmosphere and the resulting health impacts. The capacity of the plant is 97,000 MT/y of copper, the average size of all existing plants without roasters. The capacity factor chosen for this plant is 0.75. Main stack heights for facilities without roasters range from 61 to 228 meters. The control equipment applied to the reference facility was chosen to represent typical equipment on actual copper smelters.

Total annual emissions of radionuclides from the reference copper smelter are given in Table 7.2-3. These values were derived from preliminary data on radionuclide releases from an existing plant. Reported release rates were adjusted to account for differences between the actual and reference facility in annual particulate emissions and total capacity.

Table 7.2-2. Reference copper smelter (TRI81)

Parameter	Value
Capacity	97,000 MT/y
Capacity factor	0.75
Type of equipment used	Reverberatory furnace
Stack Parameters	
Main stack:	
Height	150 m
Diameter	3.3 m
Exhaust gas velocity	18 m/s
Exhaust gas temperature	93° C
Acid plant	
Height	30.4 m
Diameter	1.8 m
Exhaust gas velocity	16.5 m/s
Exhaust gas temperature	79° C
Particulate Emission Rate	
Main stack:	247 kg/h
Acid plant	11 kg/h

Table 7.2-3. Radionuclide emissions from the reference copper smelter (TRI81)

Radionuclide	Emissions (Ci/y)
Uranium-238	1.0E-2
Uranium-234	1.0E-2
Thorium-230	1.9E-2
Radium-226	1.7E-3
Lead-210	2.0E-1
Polonium-210	2.0E-1
Thorium-232	1.3E-2
Radium-228	1.3E-2
Thorium-228	1.3E-2

7.2.6 Health Impact Assessment of the Reference Copper Smelter

The estimated radiation doses from radionuclide emissions from the reference copper smelter are listed in Table 7.2-4. These estimates are for a low population density southwestern site with a regional population of 3.6E+4.

Table 7.2-5 presents estimates of the maximum individual lifetime risk and number of fatal cancers per year of operation resulting from these doses.

Table 7.2-4. Radiation dose rates from radionuclide particulate emissions from the reference copper smelter

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	7.7E-2	9.5E-1
Red marrow	1.2E-1	2.6E-1
Endosteal	3.4E-1	2.8
Breast	9.7E-2	7.5E-2
Liver	1.6E-1	3.2E-1
Weighted sum	1.1E-1	4.3E-1

Table 7.2-5. Fatal cancer risks from radionuclide emissions from the reference copper smelter

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Particulates	2E-6	6E-5

7.2.7 Health Impact Assessment of Surveyed Plants

EPA has recently carried out radionuclide measurement studies at both an underground copper mine and mill and an open pit copper mine and mill. A report on these studies was completed in November 1982 (EPA82). This report provides information on the radionuclide concentrations of process samples and annual radionuclide emission rates to air. Results from these measurement studies and an assessment of the health risks from the measured emissions for a generic site are presented in this section.

Table 7.2-6 lists the uranium-238 and thorium-232 concentrations in the process samples from both the underground mine and mill and the open pit mine and mill.

Table 7.2-6. Radionuclide concentrations in surveyed copper mine and mill process samples (EPA82)

Type of Sample	Underground mine and mill		Open pit mine and mill	
	Uranium-238 (pCi/g)	Thorium-232 (pCi/g)	Uranium-238 (pCi/g)	Thorium-232 (pCi/g)
Ore	0.79	0.62	2.2	3.1
Concentrate	0.65	0.07	1.4	1.1

Underground Mine and Mill

The underground mine selected for this survey was an underground copper-iron-zinc-sulfide mine. The Mine Safety and Health Administration (MSHA) had reported average radon decay product measurements of 0.087 WL with a maximum of 0.21 WL. The ore runs less than 1 percent copper, less than 1 percent zinc, 20 percent iron, and 25 percent sulfur. A mill and flotation plant produces concentrates of the three sulfides. The uranium decay chain nuclides were at or slightly above the average concentrations found in natural rock. The ore concentration averaged about 1 pCi/g (see Table 7.2-6).

The radionuclide emissions from the underground mine and mill consisted primarily of radon-222 released from the mine exhausts (Table 7.2-7). The radon decay product exposures from these emissions are listed in Table 7.2-8. These estimates are for a low population density southwestern site with a regional population of 3.6E+4. The maximum individual lifetime risk and number of fatal cancers per year of operation from these exposures are listed in Table 7.2-9.

Table 7.2-7. Radionuclide emissions from the surveyed underground copper mine (EPA82)

Radionuclide	Emissions (Ci/y)
Radon-222	6.5

Table 7.2-8. Annual radon decay product exposures from radon-222 emissions from the surveyed copper mine[a]

Source	Maximum individual (WL-y)	Regional population (person-WL-y)
Mine vent	6.5E-5	1.3E-3

[a] Based on a ground level release.

Table 7.2-9. Fatal cancer risks from radionuclide emissions from the surveyed copper mine

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Radon-222	1E-4	3E-5

Open Pit Mine and Mill

Radionuclide emissions from the copper mill associated with the surveyed open pit mine are listed in Table 7.2-10. Particulate emissions containing radionuclides are released primarily from the crushing operations and truck hoppers. Radon-222 flux measurements of the open pit mine surfaces did not identify any quantifiable radon-222 emissions (above natural levels) from the pit. The estimated radiation dose rates and radon-222 decay product exposures from the radionuclide emissions from the surveyed copper mill are listed in Table 7.2-11 and 7.2-12. These estimates are for a low population density southwestern site with a regional population of 3.6E+4. The maximum individual lifetime risk and number of fatal cancers per year of operation from these exposures are shown in Table 7.2-13.

Table 7.2-10. Radionuclide emissions from surveyed copper mill (EPA82)

Radionuclide	Emissions (Ci/y)
Uranium-238	3.1E-4
Uraniium-234	3.8E-4
Radium-226	1.8E-4
Radon-222	1.9
Lead-210	8.9E-4

Table 7.2-11. Radiation dose rates from radioactive particulate emissions from the surveyed copper mill[(a)]

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	3.3	6.1E-2
Red Marrow	3.2E-2	1.9E-3
Endosteal	1.3E-1	1.6E-2
Breast	2.2E-2	7.3E-4
Liver	3.8E-2	3.2E-3
Weighted sum	9.7E-1	1.9E-2

(a) Based on a 10-meter stack height.

Table 7.2-12. Annual radon decay product exposures from radon-222 emissions from the surveyed copper mill

Source	Maximum individual (WL-y)	Regional population (person-WL-y)
Stack	8.3E-6	3.7E-4

Table 7.2-13. Fatal cancer risks from radionuclide emissions from the surveyed copper mill

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Particulates	1E-5	3E-6
Radon-222	1E-5	9E-6
Total	2E-5	1E-5

REFERENCES

EPA82 Environmental Protection Agency, Emissions of Naturally Occurring Radioactivity from Aluminum and Copper Facilities, EPA 520/6-82-018, Las Vegas, Nevada, November 1982.

Sc79 Schroeder H. J., Mineral Commodity Profiles--Copper, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1979.

TRI81 Teknekron Research, Inc., Draft, Partial and Supplemental Background Information Document--Primary Pyrometallurgical Extraction Process, Report to the Environmental Protection Agency under Contract No. 68-01-5142, USEPA Docket Number A-79-11, May 1981.

7.3 Zinc Industry

7.3.1 General Description

Zinc is usually found in nature as a sulfide ore called sphalerite. The ores, which usually contain impurities of lead, cadmium, and traces of other elements, are processed at the mine to form concentrates typically containing 62 percent zinc and 32 percent sulfur. These concentrates are processed at the smelter to recover zinc metal.

The five operating primary zinc production facilities in the United States and their capacities are listed in Table 7.3-1. Total production capacity for primary zinc in 1980 was 401,000 metric tons. The domestic demand for zinc is expected to grow at a rate of about 2 percent per year through 1985 (Ca78).

In the past 10 years, U.S. demand for zinc metal has grown slowly, but U.S. smelting capacity has declined by over 50 percent. Plants closed because they were obsolete, could not meet environmental standards, or could not obtain sufficient concentrate feed. Consequently, the metal has replaced concentrate as the major form of import. This situation is expected to continue.

7.3.2 Process Description

A zinc smelter produces 99.99+ percent zinc from the approximately 62 percent zinc concentrate feed produced by the mill. The zinc concentrates are roasted at approximately 600° C to convert sulfur to sulfur dioxide and to produce an impure zinc oxide or calcine. The calcine is transferred to tanks, leached with dilute sulfuric acid, and treated with a small amount of zinc oxide dust to remove impurities, such as lead, gold, and silver.

The leaching step varies somewhat from plant to plant, but the basic process of selective precipitation of the impurities from the leach solution remains the same. This solution is purified and piped to electrolytic cells, where the zinc is electro-deposited on aluminum cathodes. Domestic zinc smelters use electrolytic reduction to reduce the quantity of sulfur and particulate emissions.

The cathodes are lifted from the tanks at intervals and stripped of the zinc, which is melted in a furnace and cast into slabs. Electrolysis of the solution regenerates sulfuric acid which is used in succeeding cycles of leaching.

7.3.4 Control Technology

Ore concentrates are heated in roasters to temperatures ranging from 500° C to 700° C to remove most of the sulfur in the sulfide

Table 7.3-1. Location and size of primary zinc production plants[a] (TRI81)

Location	Company	First year of operation	Capacity (Thousands of MT)
Idaho Kellogg[b]	Bunker Hill	1928	95
Illinois Sauget	AMAX	Rebuilt in 1970's	76
Oklahoma Bartlesville	National	1976	51
Tennessee Clarksville	Jersey Miniere	1978	81
Texas Corpus Christi	Asarco	1942	98
Total			401

[a] All plants use the electrolytic process.
[b] Plant is now shut down.

ore and form calcine. Roaster off-gases containing sulfur dioxide are treated in single or double contact acid plants. The off-gas also contains significant amounts of calcine, which is recovered in waste heat boilers, cyclones, and ESP's and then recycled. In addition, most acid plants have wet scrubbers, wet ESP's, and demisting towers before the plant catalyst to remove residual particulate matter which could foul the catalyst bed.

The electrolytic (or hydrometallurgical) zinc smelting process is a minor source of particulate emissions, and is not serviced by a particulate control device (TRI81).

7.3.5 Radionuclide Emissions

Particulate material emitted from a zinc smelter contains radionuclides in concentrations similar to or greater than the concentrations in the materials processed. Because of the high temperatures to which the concentrates are heated, some of the radionuclides (particularly lead-210 and polonium-210) may be volatilized and released in greater quantities than the other radionuclides in the ore concentrates. Although EPA has recently measured the radionuclide emissions from a zinc smelter, the results of these measurements are not yet available. Therefore, the radionuclide emissions for the reference plant are based on estimates of particulate emissions and enrichment factors for radionuclides which may be volatilized during processing of the ore concentrates (TRI81).

Control systems which control particulates will also control radionuclide emissions. Particulate material in the roaster off-gases is generally removed via a combination of cyclones, scrubbers, and electrostatic precipitators. The off-gases are then treated in an acid plant and released. As far as can be determined, off-gases from the electrolytic process itself are vented directly to the atmosphere.

7.3.6 Reference Facility

Table 7.3-2 describes the parameters of a reference zinc smelter which were used to estimate the radioactive emissions to the atmosphere and the resulting health impacts.

The reference zinc smelter has a total production capacity of about 88,000 MT/y, typical of the industry. The plant produces zinc by electrolytic reduction and operates at an annual capacity factor of 0.80, the 1976 industry-wide average (DOI76). The flow rate was derived by adjusting available data for differences in capacity and capacity factor. The stack height was estimated from available data. This value, in turn, was used to estimate the stack diameter.

Table 7.3-2. Reference zinc plant (TRI81)

Parameter	Value
Process	Electrolytic reduction
Capacity	88 E+3 MT/yr zinc
Capacity factor	0.8
Radionuclide concentration of input ore	
Uraniuim-238	0.43 pCi/g
Thorium-232	0.35 pCi/g
Stack Parameters	
Number	1
Height	61 meters
Diameter	2.4 meters
Exhaust gas velocity	2.7 m/s
Exhaust gas temperature	93° C

Roaster off-gases are treated for dust removal by a cyclone in series with an electrostatic precipitator. The cleaned gases are then passed through a sulfur dioxide (SO_2) plant. Off-gases from the electrolytic reduction step are vented directly to the atmosphere.

The total annual radionuclide emissions for the reference zinc smelter are listed in Table 7.3-3.

Table 7.3-3. Radionuclide emissions from the reference zinc smelter (TRI81)

Radionuclide	Emissions (Ci/y)
Uranium-238	2.6E-4
Uranium-234	2.6E-4
Thorium-230	1.3E-4
Radium-226	1.9E-4
Lead-210	6.5E-4
Polonium-210	6.5E-5
Thorium-232	7.9E-5
Radium-228	7.9E-5

7.3.6. Health Impact Assessment of Reference Zinc Smelter

The estimated annual radiation doses from radionuclide emissions from the reference zinc smelter are listed in Table 7.3-4. These estimates are for a rural site with a regional population of 6E+5. The maximum individual lifetime risk and number of fatal cancers per year of operation of the reference plant are shown in Table 7.3-5.

Table 7.3-4. Radiation dose rates from radionuclide emissions from the reference zinc smelter

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	7.4E-3	7.4E-1
Red marrow	1.1E-2	7.6E-2
Endosteal	6.6E-2	8.0E-1
Breast	6.1E-3	2.6E-2
Liver	1.4E-2	4.0E-2
Weighted sum	9.1E-3	2.6E-1

Table 7.3-5. Fatal cancer risks from radionuclide emissions from the reference zinc smelter

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Particulates	1E-7	4E-5

7.3.7 Health Impact Assessment of Surveyed Plants

EPA has recently carried out measurements at a zinc mine and mill. A report on these measurements was issued in November 1982 (EPA82). This report provided information on the radionuclide concentrations in process samples and on annual radionuclide emissions to air. The zinc mine and mill surveyed were chosen because of their high production rates and the high WL measurements in the mine reported by the Mine Safety and Health Administration. Results of these measurements and an assessment of the health risks from these emissions for a generic site are presented in this section.

Table 7.3-6 lists the uranium-238 and thorium-232 concentrations in process samples from the mine and mill.

Table 7.2-6. Radionuclide concentrations in surveyed zinc mine and mill process samples (EPA82)

Type of Sample	Concentration (pCi/g)	
	Uranium-238	Thorium-232
Ore	0.18	0.08
Concentrate	0.16	0.04

Zinc Mine

Measurements of the radionuclide emissions from the zinc mine showed radon-222 to be the principal radionuclide emitted to air. Other radionuclides were emitted in much smaller quantities. Table 7.3-7 lists the radionuclide emissions from the surveyed zinc mine. The estimated annual radiation doses and radon decay product exposures from these emissions are presented in Tables 7.3-8 and 7.3-9. These estimates are for a rural site with a regional population of 6E+5. The maximum individual lifetime risks and number of fatal cancers per year of operation of the zinc mine are shown in Table 7.3-10.

Table 7.3-7. Radionuclide emissions from the surveyed zinc mine (EPA82)

Radionuclide	Emissions (Ci/y)
Uranium-238	1.2E-7
Uranium-234	1.2E-7
Thorium-230	1.0E-7
Radium-226	7.0E-8
Radon-222	2.3E+2
Lead-210	3.2E-7
Polonium-210	1.5E-7
Thorium-232	5.0E-8

Table 7.3-8. Radiation dose rates from radioactive particulate emissions from the surveyed zinc mine[(a)]

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	2.4E-3	9.1E-4
Red marrow	7.2E-4	3.9E-4
Endosteal	4.6E-3	1.6E-3
Breast	4.1E-4	2.8E-4
Liver	4.0E-4	2.5E-4
Weighted sum	1.1E-3	4.8E-4

[(a)] Based on ground level release.

Table 7.3-9. Annual radon decay product exposures from radon-222 emissions from the surveyed zinc mine

Source	Maximum individual (WL-y)	Regional population (person-WL-y)
Mine vent	1.2E-3	8.6E-1

Table 7.3-10. Fatal cancer risks from radionuclide emissions from the surveyed zinc mine

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Particulates	1E-8	1E-7
Radon-222	2E-3	2E-2
Total	2E-3	2E-2

Zinc Mill

Table 7.3-11 lists the radionuclide emissions from the surveyed zinc mill. The small emissions reflect the low radionuclide concentration of the zinc ore and the low particulate emissions from the plant. The estimated annual radiation doses and radon decay product exposures from these emissions are presented in Table 7.3-12 and 7.3-13. These estimates are for a rural site with a regional population of 6E+5. The maximum individual lifetime risk and number of fatal cancers per year of operation from these exposures are shown in Table 7.3-14.

Table 7.3-11. Radionuclide emissions from the surveyed zinc mill (EPA82)

Radionuclide	Emissions (Ci/y)
Uranium-238	1.7E-6
Uranium-234	1.7E-6
Thorium-230	1.4E-6
Radium-226	7.5E-7
Radon-220	1.0
Lead-210	1.3E-6
Polonium-210	2.0E-6
Thorium-232	5.1E-7

Table 7.3-12. Radiation dose rates from radioactive particulate emissions from the surveyed zinc mill[a]

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	5.8E-3	1.0E-2
Red marrow	7.5E-4	1.3E-3
Endosteal	1.1E-2	1.8E-2
Breast	8.2E-5	1.5E-4
Liver	1.6E-4	2.0E-4
Weighted sum	2.0E-3	3.6E-3

(a)Based on a 15-meter stack height.

Table 7.3-13. Annual radon decay product exposures from radon-222 emissions from the surveyed zinc mill

Source	Maximum individual (WL-y)	Regional population (person-WL-y)
Zinc mill	9.9E-7	3.5E-3

Table 7.3-14. Fatal cancer risks from radionuclide emissions from the surveyed zinc mill

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Particulates	2E-8	5E-7
Radon-222	2E-6	8E-5
Total	2E-6	8E-5

REFERENCES

Ca78 Cammarota V. A., Jr., Mineral Commodity Profiles-Zinc, MCP-12, U.S. Department of the Interior, Bureau of Mines, May 1978.

DOI76 Department of Interior, Preprint from the 1976 Bureau of Mines Minerals Yearbook: Zinc, Washington, D.C., 1976.

EPA82 Environmental Protection Agency, Emissions of Naturally Occurring Radioactivity: Underground Zinc Mine and Mill, EPA 520/6-82-020, Las Vegas, Nevada, November 1982.

TRI81 Teknekron Research, Inc., Draft, Partial and Supplemental Background Information Document--Primary Pyrometallurgical Extraction Process, Report to Environmental Agency under Contract No. 68-01-5142, USEPA Dosket Number A-79-11, May 1981.

7.4 Lead Industry

7.4.1 General Description

Galena (PbS), frequently containing cerussite ($PbCO_3$) and anglesite ($PbSO_4$), is the principal lead-bearing ore found in nature. A sulfide ore, galena contains small amounts of copper, iron, zinc, and other trace elements (EPA75). In the smelting process, lead bullion (95-99 percent lead metal) is separated from ore concentrates (45-80 percent lead).

Table 7.4-1 lists the location and size of the primary lead smelters. Three facilities have integrated smelter/refinery complexes and two facilities (ASARCO's El Paso and East Helena smelters) ship their drossed lead bullion to the company's Omaha refinery for final processing. Refinery operations, including those co-located with smelters, are not considered part of the primary lead source category.

Three of the smelters are located in southeastern Missouri and process only ores from the Missouri lead belt. The smelters located in Texas and Montana are custom smelters, designed to handle larger variations in ore composition than the Missouri smelters. Both domestic and foreign ores are smelted at the western plants.

The design capacities of the primary lead smelters, expressed as annual lead metal output, range from 82,000 to 204,000 tons. Total production from primary smelters in 1979 was 594,000 tons (DOC80).

7.4.2 Process Description

Lead smelting involves three distinct processes: sintering, to convert the ore from a sulfide to an oxide or sulfate form and prepare the feed materials for furnacing; furnacing, to reduce the oxide feed to lead metal; and drossing, to reduce the copper content of the lead bullion from the furnace. After drossing, additional refining steps, as dictated by the specific impurities present and the intended end-use of the product, are performed to yield the purified lead metal.

7.4.3 Control Technology

Off-gases from the sintering machine and the blast furnace are the most significant sources of particulate emissions from the lead smelting process; together these two sources account for more than 95 percent of particulate emissions.

Table 7.4-1. Location and size of primary lead production plants (TRI81)

Location	Company	First year of operation	Capacity (Thousands of tons of Pb)
Idaho			
Kellogg[(a)]	Bunker Hill	1917	117
Missouri			
Boss	Amax-Homestake	1968	127
Glover	ASARCO	1968	100
Herculanium	St. Joe Minerals	1892 rebuilt 1970's	204
Montana			
East Helena	ASARCO	1888	82
Texas			
El Paso	ASARCO	1887	82

(a) Now shut down.

Sintering Machines

Particle size distribution of particulate matter entrained in off-gas from sintering machines indicated that the majority of particles are less than 10 microns in diameter. This relatively small particle size precludes the use of mechanical collectors or wet scrubbing systems, which decrease in efficiency substantially with decreasing size of the particle collected. Consequently, five of the six existing lead sintering machines use fabric filters for particulate emission control; the sixth employs an ESP (IERL79). The final control devices, in many cases, are preceded by ballon flues or settling chambers for gravitational collection of more massive particles before off-gases enter the ESP or fabric filter.

Sinter off-gas is typically fed to an acid plant for recovering of sulfur dioxide after particulate cleaning, as described above. Efficient operation of the acid plant requires gases containing 5 percent or more SO_2. The circuit of gases through the sinter machine may be quite complex with weak (in SO_2) gases being recirculated through an upstream section of the machine to enrich the SO_2 content before going to the acid plant.

Blast Furnaces

The majority of particles in the lead blast furnace off-gas are smaller than 10 microns in diameter. Consequently, all blast furnace systems currently in operation are serviced by baghouses. The particulate collection efficiencies of baghouses treating lead blast furnace off-gas is roughly 99 percent.

7.4.4 Radionuclide emissions

Particulate material emitted from a lead smelter contains radionuclides in concentrations similar to or greater than the concentrations in the materials processed. Since enrichment takes place when nuclides volatilize during the high-temperature phase of production, the concentration of some radionuclides will be higher in the particulates than in the original ore. Although EPA has recently measured the radionuclide emissions at a lead smelter, results of these measurements are not yet available. Therefore, the releases for the reference lead smelter have been calculated by assuming that the radionuclide content in the particulate released is the same as that in the input ore and applying the appropriate enrichment factors for volatile radionuclides. Multiplying the concentrations of radionuclides in the ore by the total annual particulate release then yields the total annual radionuclide release.

The particulate emission rates and enrichment factors used in estimating the emissions from the reference plant were taken from TRI81.

7.4.5 Reference Facility

Table 7.4-2 describes the parameters of the reference facility which were used to estimate the radioactive emissions to the atmosphere and the resulting health impacts.

The reference lead smelter has a capacity of 107,000 MT lead per year, typical of existing plants. The plant operates at a load factor of 0.92 which was the industry-wide average for 1979 (DOC80). There are two stacks at the plant--a main stack and an acid plant tail gas stack. The height of the main stack was chosen by averaging the heights of all stacks in the industry.

The particulate emissions and flow rate through the stack were determined by taking weighted averages of values of the actual facilities.

Table 7.4-2. Reference lead smelter (TRI81)

Parameter	Value
Capacity	1.07E+3 MT/yr lead
Capacity factor	0.92
Radionuclide concentration of input ore:	
Uranium-238	0.43 pCi/g
Thorium-232	0.35 pCi/g
Stack Parameters	
Number	2
Main stack	
Height	38 meters
Diameter	1.8 meters
Exit gas velocity	14.7 m/s
Exhaust gas temperature	149 °C
Acid plant stack	
Height	30 meters
Diameter	1.8 meters
Exhaust gas velocity	1.7 m/s
Exhaust gas temperature	93 °C

Table 7.4-3. Radionuclide emissions from the reference lead plant (TRI81)

Radionuclide	Emissions(a) (Ci/y)
Uranium-238	1.1E-4
Uranium-234	1.1E-4
Thorium-230	5.5E-5
Radium-226	8.2E-5
Lead-210	2.7E-4
Polonium-210	2.7E-4
Thorium-232	4.4E-5
Radium-228	4.4E-5

(a)Main stack only.

7.4.6 Health Impact Assessment of Reference Smelter

The estimated radiation doses from radionuclide emissions from the reference lead smelter are listed in Table 7.4-4. These estimates are for a rural site with a regional population of 2.9E+5 (rural central site from TRI81).

Table 7.4-5 presents estimates of the maximum individual lifetime risk and number of fatal cancers per year of operation of the reference smelter.

Table 7.4-4. Radiation dose rates from radionuclide emissions from the reference lead smelter (TRI81)

Organ	Maximum individual (mrem/y)	Regional population (person-rem/y)
Lung	5.6E-2	9.8E-2
Red marrow	4.7E-3	1.3E-2
Endosteal	7.1E-2	1.7E-1
Muscle	3.8E-4	3.2E-3
Liver	7.3E-4	1.1E-2

Table 7.4-5. Fatal cancer risks due to radionuclide emissions from the reference lead smelter (TRI81)

Source	Lifetime risk to maximum individual	Regional population (Fatal cancers/y of operation)
Lead smelter	2E-7	5E-6

REFERENCES

DOC80 U.S. Department of Commerce, U.S. Industrial Outlook for 200 Industries with Projections for 1984, Washington, D.C., 1980.

EPA75 Environmental Protection Agency, Development for Interim Final Effluent Limitations Guidelines and Proposed New Source Performance Standards for the Lead Segment of the Nonferrous Metals Manufacturing Point Source Category, EPA 440/ 1-75/032-9, Washington, D.C., February 1975.

IERL79 Industrial Environmental Research Laboratory, Control of Particulate Emissions in the Primary Nonferrous Metals Industries, NTIS Report No. PB-80-151822, Cincinnati, Ohio, December 1979.

TRI81 Teknekron Research, Inc., Draft, Partial and Supplemental Background Information Document--Primary Pyrometallurgical Extraction Process, Report to Environmental Agency under Contract No. 68-01-5142, USEPA Dosket Number A-79-11, May 1981.

APPENDIX A

ASSESSMENT METHODOLOGY

APPENDIX A: ASSESSMENT METHODOLOGY

CONTENTS

Page

A.1 Introduction A-5

A.2 Reference Facility A-5

A.3 Generic Sites A-5

A.4 Source Characterization A-6

A.5 Environmental Pathway Modeling Computer Programs A-6

A.6 Individual Assessment A-11

A.7 Collective Assessment A-11

A.8 AIRDOS-EPA Parameters and Input Data A-12

A.9 DARTAB--Dose and Risk Tables A-15

References A-23

TABLES

A-1 Characteristics of the generic sites A-7

A-2 Sources of food for the maximum individual A-12

A-3 Some site parameters used with AIRDOS-EPA A-13

A-4 Cattle densities and vegetable crop distributions for use with AIRDOS-EPA A-16

A-5 Site independent parameters used for AIRDOS-EPA generic site assessments A-18

A-6 Element dependent factors used in AIRDOS-EPA assessments A-20

A-7 Weighting factors used for weighted sum dose equivalent A-22

Preceding page blank

Appendix A: ASSESSMENT METHODOLOGY

A.1 Introduction

The general methodology used in the generic assessments presented in this report consisted of the following parts:

1) a description of a reference facility for the source category,

2) a choice of one or more generic sites appropriate to the source category,

3) an assignment of a source term (Ci/y) and source related quantities (e.g., release height, plume rise),

4) a calculation of individual and collective doses and risks due to air immersion, ground surface exposure, inhalation, and ingestion of radionuclides,

Assumptions made at each step were intended to be realistic without underestimating the impact of a release. The following sections describe these steps in more detail. (See Appendix B for health risk assessment details.)

A.2 Reference Facility

For each source category, a reference facility was designated. In some instances (e.g., nuclear power plants), extensive information was available on release rates and source considerations influencing dispersion (e.g., release height and exit velocity). In such cases, a reference facility was designed to represent an average facility for the source category. For other source categories (e.g., radiopharmaceutical industry), industry wide information was sparse. In these cases, data for a particular facility considered representative of the source category were used for the assessment.

A.3 Generic Sites

Generic sites were characterized for the purpose of assessing different source categories. These sites were chosen by

Preceding page blank

first identifying locations of facilities within each source category and then identifying a few of them which typified the types of locations where such facilities might be located. Factors which entered into this judgment included geographic location, population density, and food crop production.

On the basis of similarities between representative sites for the different source categories, seven generic sites (designated A, B, C, D, E, F, and G) were chosen which were believed to adequately represent potential sites for all of the source categories considered. For some source categories, one site was sufficient (e.g., uranium mining) while others required several sites to represent the source category (e.g. fossil fuel power plants). While the data used to characterize the generic sites were obtained for specific locations, there would not necessarily be a facility at that location for any specific source category.

Sites A and B represent urban and suburban locations, respectively. Site A characterizes a very large metropolitan city: the maximum case with respect to population density and overall population within 80 km (New York City, New York). Site B represents the near suburbs of a large Midwest city (St. Louis, Missouri). Site C was selected to depict the phosphate industry since this location has a heavy concentration of phosphate mining and milling (Polk County, Florida, near Bartow). Site D represents a rural setting in the central portion of the United States (near Little Rock, Arkansas). Site E exhibits the characteristics associated with the uranium industry and other mining endeavors (Grants, New Mexico). Site F is a remote, sparsely populated location in the Northwest which represents a minimal impact on the general population (near Billings, Montana). Site G (near Pocatello, Idaho) is representative of elemental phosphorous processing sites. Table A-1 gives the important characteristics of these generic sites.

A.4 Source Characterization

Sources were characterized by the release rate (Ci/year) of each emitted radionuclide. An effective release height was assigned to each source based on the release height and any expected plume rise. In general, no credit was given for plume rise unless it was clearly indicated.

A.5 Environmental Pathway Modeling Computer Programs

AIRDOS-EPA (Mo79) was used to calculate the individual and collective radionuclide concentrations for these assessments. Decay product concentrations (in working level units) associated with radon-222 were calculated on the assumption of a 70 percent equilibrium, a value considered representative of indoor exposure conditions (Ge78).

Table A-1. Characteristics of the generic sites

Site A--New York	
Meteorological data:	New York/LaGuardia (WBAN=14732)
Stability Categories:	A-F
Period of Record:	65/01-70/12
Annual Rainfall:	102 cm
Average Temperature:	12.1° C
Average Mixing Height:	1000 m
Population (0-8 km):	9.23E+5 persons
(0-80 km):	1.71E+7 persons
Dairy Cattle (0-80 km):	1.72E+5 head
Beef Cattle (0-80 km):	1.17E+5 head
Vegetable Crop Area: (0-80 km)	3.77E+4 ha

Site B--Missouri	
Meteorological data:	St. Louis/Lambert (WBAN=13994)
Stability Categories:	A-G
Period of Record:	60/01-64/12
Annual Rainfall:	102 cm
Average Temperature:	11.5° C
Average Mixing Height:	600 m
Population: (0-8 km):	1.34E+4 persons
(0-80 km):	2.49E+6 persons
Dairy Cattle (0-80 km):	3.80E+4 head
Beef Cattle (0-80 km):	6.90E+5 head
Vegetable Food Crop Area: (0-80 km)	1.64E+4 ha

Table A-1. Characteristics of the generic sites--continued

Site C--Florida

Meteorological data:	Orlando/Jet Port (WBAN=12815)
Stability Categories:	A-E
Period of Record:	74/01-74/12
Annual Rainfall:	142 cm
Average Temperature:	22.0° C
Average Mixing Height:	1000 m
Population: (0-10 km):	1.55E+3 persons
(0-80 km):	1.41E+6 persons
Dairy Cattle (0-80 km):	2.75E+4 head
Beef Cattle (0-80 km):	2.57E+5 head
Vegetable Crop Area: (0-80 km)	1.39E+4 ha

Site D--Arkansas

Meteorological data:	Little Rock/Adams (WBAN=13963)
Stability Categories:	A-F
Period of Record:	72/02-73/02
Annual Rainfall:	127 cm
Average Temperature:	14.8° C
Average Mixing Height:	600 m
Population: (0-8 km):	1.18E+4 persons
(0-80 km):	5.92E+5 persons
Dairy Cattle (0-80 km):	1.19E+4 head
Beef Cattle (0-80 km):	2.57E+5 head
Vegetable Crop Area: (0-80 km)	2.94E+3 ha

Table A-1. Characteristics of the generic sites--continued

Site E--New Mexico

Meteorological data: Stability Categories:	Grants/Gnt-Milan (WBAN=93057) A-F
Period of Record:	54/01-54/12
Annual Rainfall:	20 cm
Average Temperature:	13.2° C
Average Mixing Height:	800 m
Population: (0-8 km): (0-80 km):	0 persons 3.60E+4 persons
Dairy Cattle (0-80 km): Beef Cattle (0-80 km):	2.30E+3 head 8.31E+4 head
Vegetable Crop Area: (0-80 km)	2.78E+3 ha

Site F--Montana

Meteorological data: Stability Categories:	Billings/Logan (WBAN=24033) A-F
Period of Record:	67/01-71/12
Annual Rainfall:	20 cm
Average Temperature:	8.1° C
Average Mixing Height:	700 m
Population: (0-8 km): (0-80 km):	0 persons 1.19E+4 persons
Dairy Cattle (0-80 km): Beef Cattle (0-80 km):	1.86E+3 head 1.47E+5 head
Vegetable Crop Area: (0-80 km)	1.77E+4 ha

Table A-1. Characteristics of the generic sites--continued

Site G--Idaho	
Meteorological data: Stability Categories:	Pocatello (WBAN=24156) A-F
Period of Record:	54/01-62/12
Annual Rainfall:	27.4 cm
Average Temperature:	7.8° C
Average Mixing Height:	615 m
Population: (0-10 km): (0-80 km):	4.17E+4 persons 1.38E+5 persons
Dairy Cattle (0-80 km): Beef Cattle (0-80 km):	1.72E+4 head 1.45E+5 head
Vegetable Crop Area: (0-80 km)	1.44E+5 ha

Air concentrations are ground level sector averages. Dispersion is calculated from annual average meteorological data. Depletion due to dry deposition and precipitation scavenging is calculated for particulates and reactive vapors. AIRDOS-EPA does not perform ingrowth calculations for airborne radionuclide chains. The air concentrations are the basis for inhalation and submersion dose calculations.

Ground surface and soil concentrations are calculated for those nuclides subject to deposition due to dry deposition and precipitation scavenging. A 100-year accumulation period was generally used unless otherwise indicated. A general soil removal rate of 0.02 y^{-1} was assumed for deposited radionuclides. Ingrowth, as well as decay and environmental removal, is calculated for members of radionuclide decay chains. AIRDOS-EPA provides no means for calculating resuspended air concentrations or subsequent redeposition to the ground surface.

The output from AIRDOS-EPA contains calculated radionuclide intakes and external exposure. This file is used as input to DARTAB (Be81) to produce the dose and risk tables used in the individual and collective assessments. The dose and risk conversion factors used for these calculations are discussed in Appendix B.

A.6 Individual Assessment

The maximum individual was assessed on the following basis:

1) The maximum individual for each source category is intended to represent an average of individuals living near each facility within the source category. The location on the assessment grid which provides the greatest lifetime risk (all pathways considered) was chosen for the maximum individual.

2) The organ dose-equivalent rates in the tables are based on the calculated environmental concentrations by AIRDOS-EPA. For inhaled or ingested radionuclides, the conversion factors are the 70-year values calculated by RADRISK (Du80). The individual dose equivalent rates in the tables are in units of mrem/y.

3) Since the risk assessment is based on an entire lifetime spent at the calculated environmental concentrations, an adult model was considered appropriate for dosimetry.

4) The individual is assumed to home-grow a portion of his or her diet consistent with the type of site. Individuals living in urban areas were assumed to consume much less home produced food than an individual living in a rural area. We assumed that in an agriculturally unproductive location, people would home-produce a portion of their food comparable to residents of an urban area, and so we used the urban fraction for such nonurban locations. The fractions of home produced food consumed by individuals for the generic sites are shown in Table A-2. Trial runs showed little difference between assuming that the balance of the maximum individual's diet comes from the assessment area or from outside the assessment area.

A.7 Collective Assessment

The collective assessment to the population within an 80 km radius of the facility under consideration was performed as follows:

1) The population distribution around the generic site was based on the 1970 census. The population was assumed to remain stationary in time.

Table A-2. Sources of food for the maximum individual

Food	Urban/Low productivity (Sites A, B, E-G)			Rural (Sites C & D)		
	F1	F2	F3	F1	F2	F3
Vegetables	.076	0.	.924	.700	0.	.300
Meat	.008	0.	.992	.442	0.	.558
Milk	0.	0.	1.	.399	0.	.601

F1 and F2 are the home-produced fractions at the individual's location and within the 80 km assessment area, respectively. The balance of the diet, F3, is considered to be imported from outside the assessment area with negligible radionuclide concentrations due to the assessed source. Fractions are based on an analysis of household data from the USDA 1965-1966 National Food Consumption Survey (USDA72).

2) Average agricultural production data for the state in which the generic site is located were assumed for all distances greater than 500 meters from the source. For distances less than 500 meters no agricultural production is calculated.

3) The population in the assessment area consumes food from the assessment area to the extent that the calculated production allows. Any additional food required is assumed to be imported without contamination by the assessment source. Any surplus is not considered in the assessment.

4) The collective organ dose-equivalent rates are based on the calculated environmental concentrations. Seventy-year dose commitment factors (as for the individual case) are used for ingestion and inhalation. The collective dose equivalent rates in the tables can be considered to be either the dose commitment rates after 100 years of plant operation, or equivalently, the doses which will become committed for up to 100 years from the time of release for one year of plant operation.

A.8 AIRDOS-EPA Parameters and Input Data

Site independent parameter values used for AIRDOS-EPA are summarized in Table A-5. Element dependent factors (Ba81) are listed in Table A-6.

Mixing Height and Deposition

Table A-3 summarizes the mixing heights, rainfall rates, and scavenging coefficients used for the generic sites. A dry deposition velocity of 0.0018 m/s was used for particulates and 0.035 m/s for reactive vapors (e.g., elemental iodine) unless otherwise indicated.

Table A-3. Some site parameters used with AIRDOS-EPA

Generic site	Average mixing height (m)	Rainfall rate (cm/y)	Scavenging coefficient (s^{-1})
Site A	1000	102	1.0E-5
Site B	600	102	1.0E-5
Site C	1000	142	1.4E-5
Site D	600	127	1.3E-5
Site E	800	20	2.0E-6
Site F	700	20	2.0E-6
Site G	615	27	2.7E-6

The average mixing height is the distance between the ground surface and a stable layer of air where no further mixing occurs. This average was computed by determining the harmonic mean of the morning mixing height and the afternoon mixing height for the location (Ho72). The rainfall rate (USGS70) determines the value used for the scavenging coefficient. Sites E through G are relatively dry locations as reflected by the scavenging coefficients.

Meteorological Data

STAR (an acronym for STability ARray) meteorological data summaries were obtained from the National Climatic Center, Asheville, North Carolina. Data for the station considered most representative for each generic site were used. Generally, these data are from a nearby airport. The station used is identified by the corresponding WBAN number in Table A-1. These data were converted to AIRDOS format wind data using the utility program listed in Appendix A of EPA80.

Dairy and Beef Cattle

Dairy and beef cattle distributions are part of the AIRDOS-EPA input. A constant cattle density is assumed except for the area closest to the source or stack in the case of a point source, i.e., no cattle within 500 m of the source. The cattle densities are provided by State in Table A-4. These densities were derived from data developed by NRC (NRC75). Milk production density in units of liters/day-square mile was converted to number of dairy cattle /square kilometer by assuming a milk production rate of 11.0 liters/day per dairy cow. Meat production density in units of kilograms/day-square mile was changed to an equivalent number of beef cattle/square kilometer by assuming a slaughter rate of .00381 day^{-1} and 200 kilograms of beef/animal slaughtered. A 180-day grazing period was assumed for dairy and beef cattle.

Vegetable Crop Area

A certain fraction of the land within 80 km of the source is used for vegetable crop production and is assumed to be uniformly distributed throughout the entire assessment area with the exception of the first 500 meters from the source. Information on the vegetable production density in terms of kilograms (fresh weight)/ day-square mile were obtained from NRC data (NRC75). The vegetable crop fractions (Table A-4) by State were obtained from the production densities by assuming a production rate of 2 kilograms (fresh weight)/year-square meter (NRC77).

Population

The population data for each generic site were generated by a computer program, SECPOP (At74), which utilizes an edited and compressed version of the 1970 United States Census Bureau's "Master Enumeration District List with Coordinates" containing housing and population counts for each census enumeration district (CED) and the geographic coordinates of the population centroid for the district. In the Standard Metropolitan Statistical Areas (SMSA) the CED is usually a "block group" which consists of a physical city block. Outside the SMSAs the CED is an "enumeration district," which may cover several square miles or more in a rural area.

There are approximately 250,000 CEDs in the United States with an average population of about 800 persons. The position of the population centroid for each CED was marked on the district maps by the individual census official responsible for each district and is based only on personal judgment from inspection of the population distribution on the map. The CED entries are sorted in ascending order by longitude on the final data tape.

The resolution of a calculated population distribution cannot be better than the distribution of the CEDs. Hence, in a metropolitan area the resolution is often as small as one block, but in rural areas it may be on the order of a mile or more.

A.9 DARTAB--Dose and Risk Tables

The intermediate output files of ingestion and inhalation intake and ground level air and ground surface concentrations of radionuclides were processed by DARTAB (Be80) using RADRISK (Du80) dose and risk conversion factors to produce the dose and risk assessments for this report.

The internal dose conversion factors are for a 70-year dose commitment. In general, the dose factors are calculated with metabolic factors and methodology very similar to that used in ICRP-30 (ICRP30). The principal differences are in some GI transfer fraction (f_1) values (e.g., uranium and transuranics) which have been chosen to be representative of environmental rather than occupational exposure settings.

Dose equivalents are calculated using a value of 20 for Q for alpha radiation. A weighted mean of the dose equivalent to the principal organs and tissues was calculated as an effective whole body dose equivalent. The weighting factors (see Table A-7) are based on the lifetime risk from a constant uniform low LET dose rate to all organs and tissues. Note that the weighting factors are unaffected by any change in the risk model which affects all organs and tissues proportionally. The resultant quantity, identified as the weighted sum in tables in the text, is risk equivalent for external low LET exposures. That is, two different external exposure conditions which provide different values for individual organ and tissue dose rates but the same value for the weighted sum, will provide, using the RADRISK methodology, the same lifetime risk. The weighted sum is conceptually to the ICRP-26 effective whole body dose equivalent (ICRP77) but with a more explicit set of organs and tissues and a different set of weighting factors.

For intakes of radionuclides where the committed dose is delivered over a considerable period of time or where both high and low LET radiation are present, the weighted sum is no longer risk equivalent. Our experience, however, is that the weighted sum is between a factor of 1 and 2 greater than the true risk equivalent low LET dose rate. Hence, the weighted sum provides a single measure of dose equivalent which approximately corresponds to risk.

Table A-4. Cattle densities and vegetable crop distributions for use with AIRDOS-EPA

State	Dairy cattle density #/km^2	Beef cattle density #/km^2	Vegetable crop fraction km^2/km^2
Alabama	7.02E-1	1.52E+1	4.16E-3
Arizona	2.80E-1	3.73	2.90E-3
Arkansas	5.90E-1	1.27E+1	1.46E-3
California	2.85	8.81	1.18E-2
Colorado	3.50E-1	1.13E+1	1.39E-2
Connecticut	2.50E-1	3.60	7.93E-3
Delaware	2.72	6.48	5.85E-2
Florida	1.37	1.28E+1	6.92E-3
Georgia	8.63E-1	1.43E+1	2.17E-3
Idaho	8.56E-1	7.19	7.15E-2
Illinois	2.16	3.33E+1	2.80E-2
Indiana	2.80	3.34E+1	2.72E-2
Iowa	3.14	7.40E+1	2.43E-2
Kansas	8.00E-1	2.90E+1	5.97E-2
Kentucky	2.57	2.65E+1	3.98E-3
Louisiana	9.62E-1	1.08E+1	4.35E-2
Maine	8.07E-1	7.65E-1	5.97E-2
Maryland	6.11	1.09E+1	1.11E-2
Massachusetts	3.13	2.90	4.96E-3
Michigan	3.51	7.90	1.70E-2
Minnesota	4.88	1.85E+2	3.05E-2
Mississippi	8.70E-1	1.75E+1	1.07E-3
Missouri	1.89	3.43E+1	8.14E-3
Montana	9.27E-2	7.29	8.78E-3
Nebraska	8.78E-1	3.50E+1	2.39E-2
Nevada	5.65E-2	1.84	8.92E-3
New Hampshire	1.58	1.40	6.69E-2
New Jersey	3.29	4.25	1.82E-2
New Mexico	1.14E-1	4.13	1.38E-3
New York	8.56	5.83	1.88E-2

Table A-4. Cattle densities and vegetable crop distributions for use with AIRDOS-EPA--continued

State	Dairy cattle density #/km^2	Beef cattle density #/km^2	Vegetable crop fraction km^2/km^2
North Carolina	1.26	1.02E+1	6.32E-3
North Dakota	6.25E-1	1.18E+1	6.29E-2
Ohio	4.56	2.03E+1	1.70E-2
Oklahoma	7.13E-1	2.68E+1	2.80E-2
Oregon	4.53E-1	4.56	1.59E-2
Pennsylvania	6.46	9.63	1.32E-2
Rhode Island	2.30	2.50	4.54E-2
South Carolina	7.02E-1	8.87	1.84E-3
South Dakota	8.85E-1	2.32E+1	1.20E-2
Tennessee	2.00E-1	2.11E+1	2.72E-3
Texas	5.30E-1	1.90E+1	5.77E-3
Utah	4.46E-1	2.84	1.83E-3
Vermont	8.88	4.71	1.08E-3
Virginia	1.84	1.31E+1	8.70E-3
Washington	1.50	5.62	5.20E-2
West Virgina	6.00E-1	6.23	1.16E-3
Wisconsin	1.43E+1	1.81E+1	1.78E-2
Wyoming	5.79E-2	5.12	1.59E-3

Table A-5. Site independent parameters used for AIRDOS-EPA generic site assessments

Symbolic variable	Description	Value
BRTHRT	Breathing Rate (cm^3/h)	9.17E+6
T	Surface buildup time (days)	3.65E+4
DDI	Activity fraction after washing	0.5
TSUBH1	Time delay-pasture grass (h)	0.0
TSUBH2	Time delay-stored food (h)	2.16E+3
TSUBH3	Time delay-leafy vegetables (h)	336.
TSUBH4	Time delay-produce (h)	336.
LAMW	Weathering removal rate factor (h^{-1})	2.10E-3
TSUBE1	Exposure period-pasture (h)	720.
TSUBE2	Exposure period-crops or leafy vegetables (h)	1.44E+3
YSUBV1	Productivity-pasture (dry weight)(kg/m^2)	.280
YSUBV2	Productivity-crops and leafy vegetables (kg/m^2)	.716
FSUBP	Time fraction-pasture grazing	0.40
FSUBS	Pasture feed fraction-while pasture grazing	0.43
QSUBF	Feed or forage consumption rate (kg-dry/day)	15.6
TSUBF	Consumption delay time-milk (d)	2.0
UV	Vegetable utilization rate (kg/y)	176.
UM	Milk utilization rate (kg/y)	112.
UF	Meat utilization rate (kg/y)	85.
UL	Leafy vegetable utilization rate (kg/y)	18.
TSUBS	Consumption time delay-meat (days)	20.

Table A-5. Site independent parameters used for AIRDOS-EPA generic site assessments (Continued)

Symbolic variable	Description	Value
FSUBG	Produce fraction (garden of interest)	1.0
FSUBL	Leafy veg fraction (garden of interest)	1.0
TSUBB	Soil buildup time (y)	100.
P	Effective surface density of soil (kg/m^2)	215.
TAUBEF	Meat herd-slaughter rate factor (d^{-1})	3.81E-3
MSUBB	Mass of meat of slaughter (kg)	200.
VSUBM	Milk production rate of cow (L/d)	11.0
R1	Deposition interception fraction-pasture	0.57
R2	Deposition interception fraction-leafy vegetables	0.20

Table A-6. Element dependent factors used in AIRDOS-EPA assessments

Element	Clearance class	F_1	F_m (d/L)	F_f (d/kg)	Biv_1	Biv_2
Ac	Y	0.10E-2	2.0E-5	1.6E-6	1.0E-2	2.5E-3
Ac	W	0.10E-2	2.0E-5	1.6E-6	1.0E-2	2.5E-3
Ag	Y	0.50E-1	3.0E-2	1.7E-2	6.0E-1	1.5E-1
Am	Y	0.10E-2	3.6E-5	1.6E-6	9.8E-3	1.5E-3
As	W	0.30E-1	6.2E-5	2.0E-3	3.9E-3	1.7E-2
Ba	D	0.10	3.5E-4	3.2E-3	6.1E-2	2.0E-1
Be	W	0.20E-2	9.1E-7	1.0E-3	1.7E-3	4.2E-4
Bi	W	0.50E-1	5.0E-4	1.3E-2	6.0E-1	1.5E-1
Ce	Y	0.10E-3	2.0E-5	1.2E-3	2.6E-2	6.2E-3
Cm	Y	0.10E-2	2.0E-5	1.6E-6	1.3E-3	1.7E-3
Co	W	0.50E-1	2.0E-3	1.3E-2	3.7E-2	9.3E-3
Co	Y	0.50E-1	2.0E-3	1.3E-2	3.7E-2	9.3E-3
Cr	D	0.10	2.0E-3	2.4E-3	2.4E-2	6.0E-3
Cr	Y	0.10	2.0E-3	2.4E-3	2.4E-2	6.0E-3
Cs	D	0.95	5.6E-3	1.4E-2	1.4E-1	9.1E-3
Eu	Y	0.10E-3	2.0E-5	4.8E-3	1.0E-2	2.5E-3
Fe	W	0.10	5.9E-5	4.0E-2	9.3E-3	2.3E-3
Ga	W	0.10E-2	5.0E-5	1.4	1.0E-3	2.5E-4
Hg	W	0.20E-1	9.7E-6	2.6E-1	1.5	3.8E-1
Ir	Y	0.10E-1	2.0E-6	1.5E-3	5.2E+1	1.3E+1
I	D	0.95	9.9E-3	7.0E-3	2.0E-1	5.5E-2
La	W	0.10E-3	2.0E-5	2.0E-4	4.2E-3	1.1E-3
La	Y	0.10E-3	2.0E-5	2.0E-4	4.2E-3	1.1E-3
Mn	W	0.10	8.4E-5	8.0E-4	3.9E-2	9.8E-3
Mo	D	0.95	1.4E-3	8.0E-3	3.4	2.2E-1
Na	D	0.95	3.5E-2	3.0E-2	2.1E-1	5.2E-2
Nb	W	0.10E-1	2.0E-2	2.8E-1	3.8E-2	9.4E-3
Pa	Y	0.10E-2	5.0E-6	1.6E-6	1.0E-2	2.5E-3
Pb	W	0.80E-1	8.7E-5	9.1E-4	1.4E-1	4.8E-3
Po	W	0.10	1.2E-4	8.7E-3	4.2E-3	2.6E-4
Po	D	0.10	1.2E-4	8.7E-3	4.2E-3	2.6E-4
Pr	Y	0.10E-3	2.0E-5	4.7E-3	1.0E-2	2.5E-3
Pu	Y	0.30E-4	5.3E-8	1.9E-8	6.7E-3	1.1E-3
P	D	0.80	1.6E-2	4.6E-2	4.4E+0	1.1
Ra	W	0.20	5.9E-4	5.0E-4	1.0E-1	2.0E-2

Table A-6. Element dependent factors used in AIRDOS-EPA assessments (Continued)

Element	Clearance class	F_1	F_m (d/L)	F_f (d/kg)	Biv_1	Biv_2
Rb	D	0.95	1.2E-2	3.1E-2	2.5E-1	6.3E-2
Ru	W	0.40E-1	6.1E-7	1.8E-3	1.7E-1	1.6E-2
Ru	Y	0.40E-1	6.1E-7	1.8E-3	1.7E-1	1.6E-2
Sb	W	0.50E-1	2.0E-5	4.0E-3	1.1E-1	2.8E-2
Sn	W	0.50E-1	1.2E-3	8.0E-2	2.0E-2	5.0E-3
Sr	D	0.20	1.1E-3	3.0E-4	2.4	2.2E-1
S	D	0.95	1.6E-2	1.0E-1	2.4	5.9E-1
Tb	Y	0.10E-3	2.0E-5	4.4E-3	1.0E-2	2.6E-3
Tc	W	0.80	9.9E-3	8.7E-3	2.2E+2	1.1
Th	W	0.10E-2	5.0E-6	1.6E-6	6.3E-3	3.5E-4
Th	Y	0.10E-2	5.0E-6	1.6E-6	6.3E-3	3.5E-4
Tl	W	0.95	2.2E-2	4.0E-2	1.0	2.5E-1
U	Y	0.20E-2	1.4E-4	1.6E-6	2.1E-2	4.2E-3
U	D	0.50E-1	1.4E-4	1.6E-6	2.1E-2	4.2E-3
Y	W	0.10E-3	2.0E-5	4.6E-3	1.1E-2	4.3E-3
Zn	W	0.50	1.0E-2	3.0E-2	3.9E-1	9.8E-2
Zr	W	0.20E-2	8.0E-2	3.4E-2	6.8E-4	1.7E-4

Table A-7. Weighting factors used for weighted sum dose equivalent

Organ or tissue	Risk[(a)] (x 10^{-5})	Weighting factor
Lung (Pulmonary)	0.608	0.2911
Breast (Muscle)	0.399	.1911
Red marrow	0.326	.1561
Endosteum	0.031	.0148
Stomach	.087	.0416
Small intestine	.017	.0081
Upper large intestine	.035	.0168
Lower large intestine	.069	.0330
Liver	.156	.0747
Kidneys	.035	.0168
Bladder	.035	.0168
Pancreas	.121	.0579
Thyroid	.085	.0407
Thymus	.017	.0081
Spleen	.017	.0081
Testes	.017	.0081
Ovaries	.017	.0081
Uterus	.017	.0081
Total	2.089	1.0000

(a)Individual lifetime risk for a low LET dose rate of 1 mrad/y (see Appendix-B).

REFERENCES

At74 Athey T. W., R. A. Tell, and D. E. Janes, 1974, The Use of an Automated Data Base in Population Exposure Calculations, from Population Exposures, Health Physics Society, CONF-74018, October 1974.

Ba81 Baes C. F. III, and R. D. Sharp, A Director of Parameters Used in a Series of Assessment Applications of the AIRDOS-EPA and DARTAB Computer Codes, ORNL-5710, Oak Ridge National Laboratory, Oak Ridge, Tennessee, March 1981.

Be81 Begovich C. L., K. F. Eckerman, E.C. Schlatter, S.Y. Ohr, and R. O. Chester, 1981, DARTAB: A program to combine airborne radionuclide environmental exposure data with dosimetric and health effects data to generate tabulation of predicted impacts. ORNL/5692, Oak Ridge National Laboratory, Tennessee, August 1981.

EPA80 Environmental Protection Agency, Radiological Impact Caused by Emissions of Radionuclides into Air in the United States, EPA 520/7-79-006, EPA, Office of Radiation Programs, Washington, D.C., December 1980.

Ge78 George A. C. and A. J. Breslin, 1978, The Distribution of Ambient Radon and Radon Daughters in Residential Buildings in the New Jersey-New York Area. Presented at Symposium on the National Radiation Environment III, Houston, Texas.

Ho72 Holzworth G. C., 1972, Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States, Report AP-101, U. S. Office of Air Programs 1972.

ICRP26 International Commission on Radiological Protection, ICRP Publication No. 26, Pergamon Press, N.Y., January 1977.

ICRP30 International Commission on Radiological Protection, ICRP Publication No. 30, Pergamon Press, N.Y.

Mo79 Moore R. E., C. F. Baes, III, L. M. McDowell-Boyer, A. P. Watson, F. O. Hoffman, J. C. Pleasant, C. W. Miller, 1979, AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides, EPA 520/1-79-009, EPA Office of Radiation Programs, Washington, D.C. 20460, December 1979.

REFERENCES (Continued)

USDA72 United States Department of Agriculture, 1972, Food Consumption of Households in the United States (Seasons and Year 1965-1966), Household Food Consumption Survey 1965-1966, Report No. 12, Agricultural Research Service, USDA, Washington, DC (March 1972).

USGS70 U.S. Geological Survey, 1970, The National Atlas, U. S. Department of the Interior, Washington, D.C.

APPENDIX B

THE BASIS FOR RISK ESTIMATES

- RADRISK CODE -

APPENDIX B: THE BASIS FOR RISK ESTIMATES

- RADRISK CODE -

CONTENTS

Page

Introduction B-5

B.1 The RADRISK Code B-6

B.2 Risk Estimates for Inhaled Radon and Radon Decay Products B-9

References B-13

TABLES

B-1 Number of premature deaths due to chronic radiation exposure by type of cancer B-7

B-2 Risk factors for high and low LET radiation by type of cancer B-8

FIGURES

B-1 Excess fatal lung cancer in various miner groups by cumulative exposure B-10

APPENDIX B: THE BASIS FOR RISK ESTIMATES

Introduction

There are two kinds of risks from the low levels of ionizing radiation characteristic of exposures to radionuclides released into the environment. The most important of these is cancer, which is fatal at least half the time. The other risk is the induction of hereditary effects in descendants of exposed persons; the severity ranges from fatal to inconsequential. We assume that at low levels of exposure the risk of cancer and hereditary effects is in proportion to the dose received, and that the severity of any induced effect is independent of the dose level. While the probability of a given type of cancer increases with dose, such a cancer induced at one dose is equally as debilitating as that same type of cancer induced at another dose. For these effects, we assume that there is no completely risk-free level of radiation exposure.

The risks and effects on health from low-level ionizing radiation were reviewed for EPA by the National Academy of Sciences in reports published in 1972 and in 1980 (NAS72a, NAS80b). We use these studies and others to estimate the risks associated with the radiation doses calculated in this report.

The individual lifetime risk is estimated for the "most exposed individuals"; these are the people at the location of highest lifetime risk. The risk to the individual is the risk of premature death from cancer due to the radiation dose. The risk calculation considers all important radionuclides, pathways, and organs of the body.

The risk to an individual can be related to other parameters. For example, we can determine which part of the risk is due to each radionuclide moving through a specific pathway or which organ is at highest risk. This information is helpful when deciding which control strategies will be the most effective.

The risk to populations is also estimated; that is, the number of future effects on health that are committed for each year that the source operates. The dose is not necessarily delivered to people during the years of release because radionuclides with long half-lives may take a long time to move through environmental pathways to people.

Like the individual lifetime risk, the total risk to populations can be related to other parameters, such as organ, radionuclide, or exposure pathway.

B.1 The RADRISK Code

The estimates of cancer risk are calculated using a computer code called RADRISK. In RADRISK, the group at risk is a hypothetical cohort of 100,000 people, all born simultaneously and subject to the same risks throughout their lives. Each member is assumed to be exposed at a constant rate to a unit concentration of radionuclides. For each radionuclide and for each pathway, the code calculates the number of premature deaths due to radiation and the number of years of life lost due to these deaths (Table B-1).

When radionuclides are inhaled, they enter the lung. The ICRP Task Group lung model is used to predict where in the lung they go and how fast they are removed to other parts of the body. Depending on the particle size and solubility in lung fluids, there is removal of some of this material to the gastrointestinal (GI) tract and absorption by the blood. A GI tract model is used to estimate how much of the material reaching the tract is absorbed by the blood.

After absorption by the blood, radionuclides are distributed among the organs according to uptake and metabolic information supplied to RADRISK. Most of this information is taken from ICRP-30 (ICRP30) supplemented with additional information summarized by EPA (Su81). Dose rates are calculated with the help of models that simulate the biological processes involved when radionuclides enter and leave organs.

Cancers do not appear immediately after exposure. There is a latent period before the cancers are observed; the length, usually years, varies with the type of cancer. Thereafter, there is a specified "plateau" period when there is a finite probability of cancer. The plateau period varies with the type of cancer.

Lifetime probabilities for many types of cancer, in many organs, are followed and risks calculated by the RADRISK code. At the same time, competing risks unrelated to the radiation exposure are accounted for. The risk factors for high and low LET radiation by type of cancer are listed in Table B-2. We believe these factors are accurate to an order of magnitude only; therefore, risk estimates are reported to only one significant figure.

A more detailed description of RADRISK can be found in ORNL/TM-7745, "Estimates of Health Risk from Exposure to Radioactive Pollutants" (Su81).

Table B-1. Number of premature deaths due to chronic radiation exposure by type of cancer

Type of cancer	Latency (years)	Plateau (years)	Number of premature deaths in cohort from chronic 1 mrad/y exposure[(a)]
Leukemia	2	25	0.326
Bone	5	304	0.031
Lung	10	110	0.608
Breast	15	110	0.399
Liver	15	110	0.154
Stomach	15	110	0.087
Pancreas	15	110	0.121
Lower large intestine	15	110	0.069
Kidneys	15	110	0.035
Bladder	15	110	0.035
Upper large intestine	15	110	0.035
Small intestine	15	110	0.017
Ovaries	15	110	0.017
Testes	15	110	0.017
Spleen	15	110	0.017
Uterus	15	110	0.017
Thymus	15	110	0.017
Thyroid	2	45	0.085

(a)Low-LET.

Table B-2. Risk factors for high and low LET radiation by type of cancer

Type of cancer	Risk factors Low-LET radiation (Deaths/10^6 rad person-y at risk)	 High-LET radiation (Deaths/10^6 rad person-y at risk)
Leukemia	2.3	46
Bone	0.2	4
Lung	3.0	30
Breast	2.3	2.3
Liver	0.9	9
Stomach	0.5	5
Pancreas	0.7	7
Lower large intestine	0.4	4
Kidneys	0.2	2
Bladder	0.2	2
Upper large intestine	0.2	2
Small intestine	0.1	1
Ovaries	0.1	1
Testes	0.1	1
Spleen	0.1	1
Uterus	0.1	1
Thymus	0.1	1
Thyroid	0.4(a)	0.4(a)

(a)0.04 for ^{131}I and longer-lived radioiodine.

B.2 Risk Estimates for Inhaled Radon and Radon Decay Products

An estimate of the health risk from inhaling radon and its short-lived decay products is done separately. The units of exposure, Working Level and Working Level Month, are unusual and do not fit into the RADRISK computer code. The risks due to exposure to radon and radon decay products have been calculated independently of the RADRISK code.

Risk of Lung Cancer from Inhaling Radon Decay Products

The high incidence of lung cancer mortality among underground miners exposed to radon decay products is well documented (EPA79a, Ar79, Ar81). Uranium miners are particularly affected, but lead, iron, and zinc miners exposed to relatively low levels of radon decay products also show an increased lung cancer mortality that correlates with exposure to radon decay products. The type of lung cancer most frequently observed, moreover, is relatively uncommon in the general population.

Risk estimates for the general public based on these studies of miners are far from precise. First, and most important, the relatively small number of miners at risk causes considerable statistical uncertainty in estimating the risk of lung cancer (see Figure B-1). Second, most miners were exposed to much higher levels of radon decay products than usually occur in the general environment. Third, the miners' exposure levels are uncertain. Fourth, significant demographic differences exist between miners and members of the general public--the miners were healthy males over 14 years old, many of whom smoked. However, we believe that information from the studies of miners provides useful estimates, if not precise predictions, of the risks to the general population from radon decay products.(1)

Since the miners have not all died, the number of eventual excess lung cancers must be projected from current data by using mathematical models. There are two ways to do this. One method, called the relative risk model, yields the percent increase in the normal incidence of cancer per unit of exposure. The other, called the absolute risk model, yields the absolute numerical increase in cancers per unit of exposure. In the relative risk model, it is assumed that the increased risk is proportional to the age-dependent natural incidence of the disease for each year an individual remains alive following exposure. In the absolute risk model, it is assumed that the added risk is constant each year an individual remains alive following exposure, i.e., independent of natural incidence.

---

(1) See "Indoor Radiation Exposure Due to Radium-226 in Florida Phosphate Lands" (EPA79a) for greater detail of such an analysis.

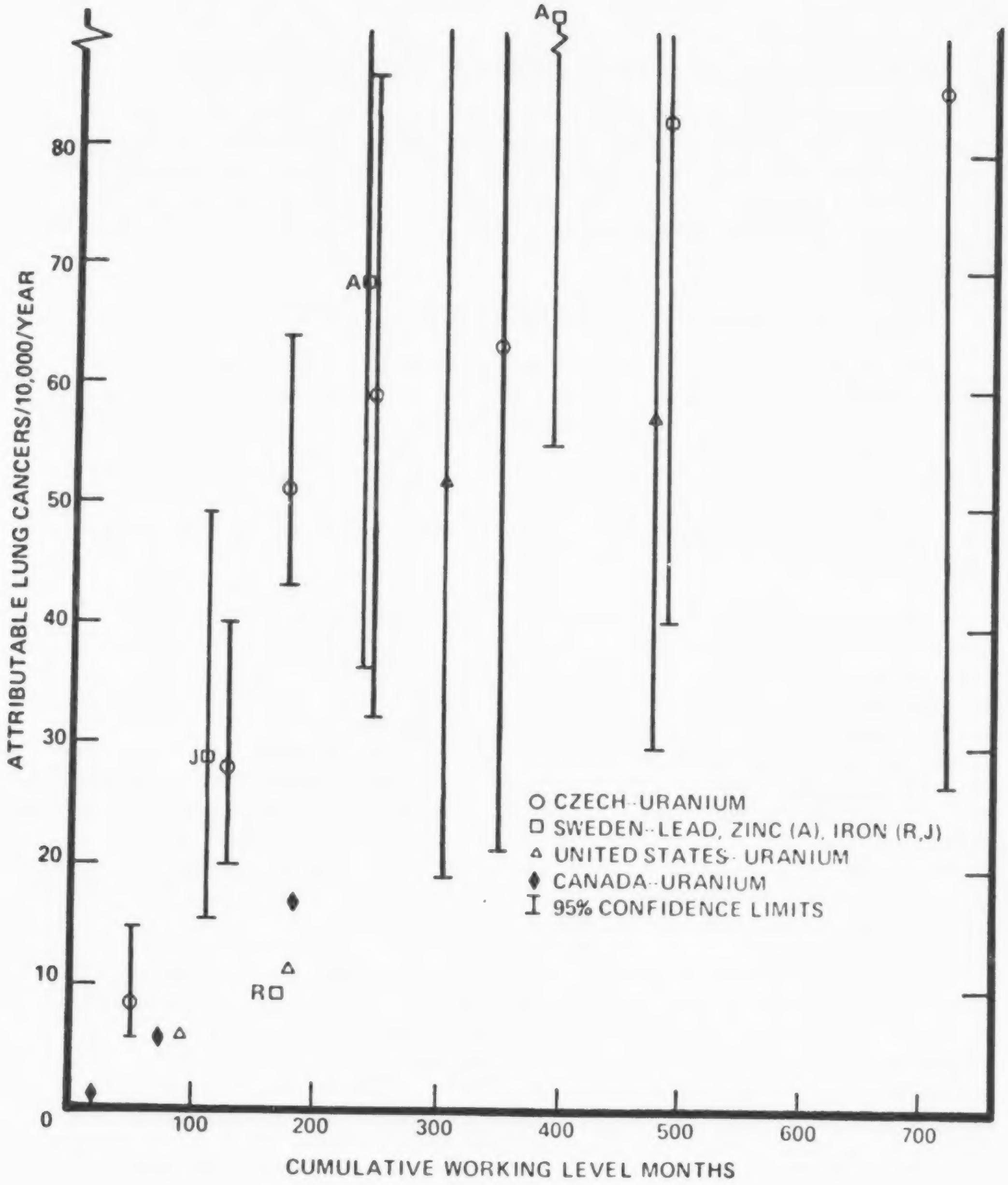


Figure B-1. Excess fatal lung cancer in various miner groups by cumulative exposure (Ar79).

When using the relative risk model, we conclude that a 3-percent increase in the number of lung cancer deaths per WLM is consistent with data from the studies of underground miners. However, because of the differences between adult male miners and the general population (EPA79a), we estimate that the risk to the general population may be as low as 1 percent or as high as 5 percent. To develop absolute risk estimates, we use the estimate of 10 lung cancer deaths per WLM for 1 million person-years at risk as reported by the National Academy of Sciences (NAS76).

In 1978, Land and Norman (La78) reported that, in Japanese A-bomb survivors, radiation-induced lung cancers had a temporal distribution of occurrence similar to naturally-occurring cancers. Further, they concluded that the cumulative distribution of radiation-induced lung cancer across time after exposure was consistent with either a relative risk model of cancer incidence or with an age-specific absolute risk model. Also in 1978, Smith and Doll (Sm78) reported the risk of cancer developing at most "heavily irradiated" sites in ankylosing spondylitic patients treated with x-rays was directly proportional to the risk of a tumor in the absence of radiation; in other words, a relative-risk response. In the most recent report on the Japanese A-bomb survivors, Kato and Schull (Ka82) repeated the observation that radiation-induced lung cancer develops only after the survivors attain the age at which this cancer normally develops. The evidence in these three reports points to relative-risk or age-specific absolute risk models as the most appropriate models for radiation-induced lung cancer.

Recent information from China provides additional evidence. Shi-quan and Xiao-ou (Sh82) have reported that in Chinese tin miners exposed to radon and its decay products, the lung cancers develop at the age at which lung cancer normally develops. Those who started mining at age 8 or 9 had an induction-latent period about 10 years longer than those who started mining at age 19 or 20. In view of these observations that a simple absolute risk model is inappropriate for estimating the risk of lung cancer due to radon decay products, we do not use it.

A comparison of risks calculated using a relative model and an age-specific absolute risk model (BEIR III, NAS80b) showed both models give numerically similar results (860 cases/10^6 person-WLM versus 850 cases/10^6 person-WLM) (RPC80). Because of the similarly in risk estimates, we use relative risk estimates for exposure to radon decay products.

To estimate the total number of lung cancer deaths from increased levels of radon decay products, we use a life-table analysis (Bu81). This analysis uses the risk coefficients just discussed. It also takes into account the length of time a person is exposed and the number of years a person survives other potential causes of death. The result is expressed as the number of premature lung cancer deaths that would occur due to lifetime radiation exposure of 100,000 persons. We assume, further, that injury caused by alpha radiation is not repairable, so that exposed persons remain at risk for the balance of their lifetimes.

To summarize, we estimate that a person exposed to 0.01 WL (0.27 WLM/y) over a lifetime incurs a 1.7 percent (1 in 60) additional chance of contracting a fatal lung cancer. This estimate is made using the relative risk model and assuming children are no more sensitive than adults. If exposure to radon decay products during childhood carries a three times greater risk, this estimated lifetime relative risk would increase by about 50 percent (EPA79a). For comparison, a lifetable analysis for the same population not exposed to excess radiation yields a 2.9-percent chance of lung cancer death.

Even though the risk of lung cancer due to radon decay products varies with age, it is sometimes convenient to express these risks on an average annual basis. We calculate a person's average annual risk from a lifetime of exposure by dividing the lifetime risk estimates given above by an average lifespan of 71 years. (Note that this is not the same as applying the risk coefficient for 71 years, since the lifetable analysis accounts for other causes of death.) Based on the risk model and assumptions just described for lifetime exposure, we estimate an average of 2.4 lung cancer deaths per year for each 100 person-working-levels of such exposure. "Person-working-levels" is the population's collective exposure; that is, the number of people times the average concentration of radon decay products (in working levels) to which they are exposed.

Radiation risk can also be stated in terms of years of life lost due to cancer death. In the relative risk model, the distribution of ages at which lung cancer caused by radiation occurs is the same as that for all lung cancer in the general population. Since lung cancer occurs most frequently in people over 70 years of age, the years of life lost per fatal lung cancer--14.5 years on the average--is less than for many other fatal cancers.

Our assessments are for current conditions because we use recent population data. If the population lifestyle, medical knowledge, and other patterns of living affecting mortality remain unchanged, then these rates of lung cancer death should persist for the indefinite future. We believe this is a prudent assumption.

REFERENCES

Ar79 Archer V.E., "Factors in Exposure Response Relationships of Radon Daughter Injury," in Proceedings of the Mine Safety and Health Administration Workshop on Lung Cancer Epidemiology and Industrial Applications of Sputum Cytology, November 14-16, 1978, Colorado School of Mines Press, Golden, Colorado, 1979.

Ar81 Archer V.E., "Health Concerns in Uranium Mining and Milling," J. Occup. Med. 23:502, 1981.

Bu81 Bunger B.M., Cook J.R. and Barrick M.K., "Life Table Methodology for Evaluating Radiation Risk: An Application Based on Occupational Exposures," in Health Physics, 40:439-455, 1981.

EPA79a Environmental Protection Agency, "Indoor Radiation Exposure Due to Radium-226 in Florida Phosphate Lands," EPA 520/6-78-013, Office of Radiation Programs, Washington, D.C., July 1979.

Ka82 Kato H. and Schull W.J., "Studies of the Mortality of A-Bomb Survivors. 7. Mortality, 1950-1978: Part 1. Cancer Mortality." Radiat. Res. 90:395-432 (1982).

ICRP79 International Commission on Radiological Protection, "Limits on Intakes of Radionuclides for Workers," A Report of Committee 2 of the ICRP, Pergamon Press, Oxford, 1979.

La78 Land C.E. and Norman J.E., "Latent Periods of Radiogenic Cancers Occurring Among Japanese A-Bomb Survivors," pp. 29-47 in Late Biological Effects of Ionizing Radiation, Volume I, IAEA, Vienna, 1978.

NAS72a National Academy of Sciences, The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, Report of the Advisory Committee on the Biological Effects of Ionizing Radiation, PB-239 735/AS, NAS, National Technical Information Service, Springfield, Virginia, 1972.

NAS72b National Academy of Sciences, "Water Quality Criteria," EPA-R3-73-033, USEPA, Washington, D.C. 1972.

NAS76 National Academy of Sciences, "Health Effects of Alpha Emitting Particles in the Respiratory Tract," Report of Ad Hoc Committee on "Hot Particles" of the Advisory Committee on the Biological Effects of Ionizing Radiations, EPA Contract No. 68-01-2230, EPA 520/4-76-013, USEPA, Washington, D.C. October 1976.

REFERENCES (Continued)

NAS80a National Academy of Sciences, "Drinking Water and Health," Volume 3, NAS, National Academy Press, Washington, D.C., 1980.

NAS80b National Academy of Sciences, "The Effects on Population of Exposure to Low Levels of Ionizing Radiation," Committee on the Biological Effects of Ionizing Radiations, NAS, National Academy Press, Washington, D.C., 1980.

Sh82 Shi-quan S. and Xiao-on Y., "Induction-Latent Period and Temporal Aspects of Miner Lung Cancer," unpublished report (in English), 1982.

Sm78 Smith P.G. and Doll R., "Age- and Time-Dependent Changes in the Rates of Radiation-Induced Cancers in Patients with Ankylosing Spondylitis Following a Single Course of X-ray Treatment," pp. 205-218 in: Late Biological Effects of Ionizing Radiation, Volume I., IAEA, Vienna, 1978.

Su81 Sullivan R.E., et al., "Estimates of Health Risk from Exposure to Radioactive Pollutants," ORNL/TM-7745, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1981.

APPENDIX C

CALCULATION OF RADON-222 CONCENTRATIONS

APPENDIX C: CALCULATION OF RADON-222 CONCENTRATIONS

The annual average radon-222 concentrations in air at various distances in each of 16 wind directions (i.e., sector segments) from an underground uranium mine vent emitting 1 kCi/y of radon-222 are presented in Table C-1. These concentrations were calculated for a 3-meter vent height using meteorological data from Grants, New Mexico (see Table A-1 of Appendix A).

Using data from Table C-1, the relationship between radon-222 concentration and distance from a mine vent can be expressed as a power function. For distances between 0.2 and 3 kilometers, the radon-222 concentration averaged over all wind directions, can be described by the following expression:

$$C_j = 0.11\ Q(X_j)^{-1.72}$$

where

C_j = radon-222 concentration in air in pCi/L at location j

X_j = distance in kilometers from mine vent to location j

Q = radon emission rate in kCi/y

Since underground uranium mines emit radon-222 to air through multiple vents rather than a single vent, the data in Table C-1 were used to estimate the radon-222 concentrations in air at various distances from a reference underground uranium mine (see Table 5-9) with 5 vents distributed as shown in Figure 5-4 and each emitting 1 kCi/y of radon-222. Examples 1 and 2 show how the data from Table C-1 were used to make these calculations.

It should be emphasized that the radon-222 concentration in air at any specific location near a uranium mine with multiple vents is highly dependent upon the spatial distribution of the vents with respect to the location of interest and the wind frequency distribution. The data in Table 5-9 illustrate the levels which could occur in a given situation.

For other situations (i.e., different spatial distribution of the vents, wind frequencies, etc.), the radon-222 concentrations in air could be higher or lower than the values shown in Table 5-9.

Example 1

Calculation of radon-222 concentrations in air at receptor location using dispersion factors based on the average of all wind directions

Source	Distance[a] (km)	Radon-222[b] (pCi/L)
Vent 1	1.3	0.07
Vent 2	1.7	0.04
Vent 3	2.1	0.03
Vent 4	1.1	0.09
Vent 5	0.5	0.37
Total		0.60

(a)Distance from vent to receptor location 0.5 km in southeasterly direction from Vent 5.

(b)Radon-222 concentrations from Table C-1 for average of all wind directions.

Example 2

Calculation of radon-222 concentrations in air at receptor location using dispersion factors based on wind frequency from each vent to the receptor location

Source	Distance[a] (km)	Direction[b]	Radon-222[c] (pCi/L)
Vent 1	1.3	S	0.07
Vent 2	1.7	SSW	0.01
Vent 3	2.1	S	0.03
Vent 4	1.1	SW	0.02
Vent 5	0.5	SE	1.32
Total			1.45

(a)Distance from vent to receptor location 0.5 km in southeasterly direction from Vent 5.

(b)Direction from vent to receptor location.

(c)Radon concentration from Table C-1 for distance and direction from each vent.

Table C-1. Annual average radon-222 concentrations in air at selected distances from an underground uranium mine vent emitting 1 kCi/y

Distance (meters)	Radon-222 air concentrations (pCi/L)			
	N	NNW	NW	WNW
100	1.46	1.96	4.60	3.22
150	1.20	1.54	3.26	2.29
200	8.89E-1	1.13	2.31	1.63
300	5.05E-1	6.38E-1	1.27	8.96E-1
400	3.18E-1	4.00E-1	7.92E-1	5.57E-1
500	2.17E-1	2.73E-1	5.38E-1	3.78E-1
800	9.38E-2	1.18E-1	2.31E-1	1.63E-1
1000	6.24E-2	7.84E-2	1.53E-1	1.08E-1
1500	3.22E-2	4.04E-2	7.85E-2	5.53E-2
2000	2.01E-2	2.53E-2	4.88E-2	3.44E-2
3000	1.03E-2	1.30E-2	2.49E-2	1.76E-2
4000	6.97E-3	8.73E-3	1.66E-2	1.17E-2
5000	5.10E-3	6.39E-3	1.21E-2	8.54E-3
8000	2.64E-3	3.31E-3	6.27E-3	4.41E-3
10000	1.94E-3	2.43E-3	4.59E-3	3.22E-3
15000	1.21E-3	1.51E-3	2.83E-3	1.99E-3
20000	8.62E-4	1.08E-3	2.02E-3	1.42E-3
30000	5.35E-4	6.69E-4	1.25E-3	8.74E-4
40000	3.79E-4	4.74E-4	8.83E-4	6.18E-4
50000	2.89E-4	3.62E-4	6.73E-4	4.71E-4

Table C-1. Annual average radon-222 concentrations in air at selected distances from an underground uranium mine vent emitting 1 kCi/y (Continued)

Distance (meters)	Radon-222 air concentrations (pCi/L)			
	W	WSW	SW	SSW
100	6.22E-1	1.51E-1	5.98E-1	5.09E-1
150	3.96E-1	1.23E-1	4.29E-1	3.94E-1
200	2.70E-1	9.14E-2	3.06E-1	2.88E-1
300	1.44E-1	5.20E-2	1.69E-1	1.62E-1
400	8.85E-2	3.27E-2	1.05E-1	1.02E-1
500	5.97E-2	2.23E-2	7.13E-2	6.93E-2
800	2.54E-2	9.66E-3	3.06E-2	2.98E-2
1000	1.68E-2	6.42E-3	2.03E-2	1.98E-2
1500	8.52E-3	3.30E-3	1.04E-2	1.02E-2
2000	5.26E-3	2.06E-3	6.44E-3	6.34E-3
3000	2.66E-3	1.06E-3	3.28E-3	3.25E-3
4000	1.76E-3	7.16E-4	2.19E-3	2.18E-3
5000	1.27E-3	5.25E-4	1.60E-3	1.59E-3
8000	6.58E-4	2.73E-4	8.31E-4	8.29E-4
10000	4.82E-4	2.00E-4	6.09E-4	6.07E-4
15000	2.95E-4	1.25E-4	3.78E-4	3.78E-4
20000	2.10E-4	8.93E-5	2.70E-4	2.70E-4
30000	1.29E-4	5.54E-5	1.67E-4	1.67E-4
40000	9.09E-5	3.93E-5	1.18E-4	1.18E-4
50000	6.91E-5	3.00E-5	8.97E-5	9.02E-5

Table C-1. Annual average radon-222 concentrations in air at selected distances from an underground uranium mine vent emitting 1 kCi/y (Continued)

Distance (meters)	Radon-222 air concentrations (pCi/L)			
	S	SSE	SE	ESE
100	2.77	5.50	8.89	5.96
150	2.18	4.23	7.30	4.91
200	1.60	3.08	5.43	3.65
300	9.01E-1	1.73	3.08	2.07
400	5.65E-1	1.08	1.94	1.30
500	3.85E-1	7.36E-1	1.32	8.89E-1
800	1.66E-1	3.17E-1	5.72E-1	3.84E-1
1000	1.10E-1	2.10E-1	3.80E-1	2.56E-1
1500	5.66E-2	1.08E-1	1.96E-1	1.32E-1
2000	3.53E-2	6.74E-2	1.23E-1	8.27E-2
3000	1.81E-2	3.46E-2	6.31E-2	4.26E-2
4000	1.22E-2	2.32E-2	4.25E-2	2.87E-2
5000	8.89E-3	1.70E-2	3.11E-2	2.11E-2
8000	4.62E-3	8.81E-3	1.62E-2	1.10E-2
10000	3.39E-3	6.46E-3	1.18E-2	8.03E-3
15000	2.12E-3	4.03E-3	7.42E-3	5.04E-3
20000	1.52E-3	2.89E-3	5.33E-3	3.62E-3
30000	9.45E-4	1.80E-3	3.32E-3	2.26E-3
40000	6.71E-4	1.28E-3	2.36E-3	1.61E-3
50000	5.13E-4	9.82E-4	1.81E-3	1.23E-3

Table C-1. Annual average radon-222 concentrations in air at selected distances from an underground uranium mine vent emitting 1 kCi/y (Continued)

Distance (meters)	Radon-222 air concentrations (pCi/L)				
	E	ENE	NE	NNE	Average
100	2.74	1.92	1.44	1.01	2.71
150	2.19	1.38	1.04	7.36E-1	2.10
200	1.61	9.81E-1	7.43E-1	5.27E-1	1.53
300	9.12E-1	5.41E-1	4.11E-1	2.92E-1	8.61E-1
400	5.72E-1	3.37E-1	2.56E-1	1.82E-1	5.39E-1
500	3.90E-1	2.29E-1	1.74E-1	1.24E-1	3.68E-1
800	1.69E-1	9.84E-2	7.48E-2	5.34E-2	1.58E-1
1000	1.12E-1	6.54E-2	4.97E-2	3.55E-2	1.05E-1
1500	5.77E-2	3.36E-2	2.54E-2	1.82E-2	5.41E-2
2000	3.61E-2	2.09E-2	1.58E-2	1.13E-2	3.38E-2
3000	1.85E-2	1.07E-2	8.10E-3	5.81E-3	1.74E-2
4000	1.25E-2	7.18E-3	5.42E-3	3.89E-3	1.17E-2
5000	9.11E-3	5.23E-3	3.95E-3	2.84E-3	8.52E-3
8000	4.73E-3	2.71E-3	2.05E-3	1.47E-3	4.42E-3
10000	3.47E-3	1.98E-3	1.50E-3	1.07E-3	3.24E-3
15000	2.16E-3	1.23E-3	9.26E-4	6.64E-4	2.02E-3
20000	1.55E-3	8.74E-4	6.59E-4	4.73E-4	1.45E-3
30000	9.63E-4	5.41E-4	4.07E-4	2.92E-4	8.98E-4
40000	6.84E-4	3.84E-4	2.88E-4	2.06E-4	6.38E-4
50000	5.22E-4	2.93E-4	2.19E-4	1.57E-4	4.88E-4